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UNIVERSITY OF ALBERTA

THE IDENTIFICATION OF PRECREMATION TRAUMA IN CREMATED BONE

BY

PAMELA MARGARET MAYNE ©

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ARTS

DEPARTMENT OF ANTHROPOLOGY

EDMONTON, ALBERTA

FALL, 1990

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The undersigned certify that they have read, and recommend to the FACULTY OF GRADUATE STUDIES AND RESEARCH for acceptance, a thesis entitled THE IDENTIFICATION OF PRECREMATION TRAUMA IN CREMATED BONE submitted by PAMELA MARGARET MAYNE in partial fulfillment of the requirements for the degree of MASTER OF ARTS.

O. B. Beattie

Ruth Gruhn
R. Gruhn

G. P. Dowling

DATE: October 1, 1990

FOR MY FATHER

FOR HE MADE ME BELIEVE

ABSTRACT

A review of the state of the art in cremation analysis reveals the omission of research directed towards the identification of precremation trauma. Research has concentrated on the visual description of the calcined bone and on the demographic data which may be retrieved. Previous studies of the fractures observed in cremated bone have been directed towards the description of the heat-induced fractures and their relationship to the body's condition before incineration. This present study investigates whether or not precremation fractures can be differentiated from heat-induced fractures in cremated bone. The physical anthropologist will be able to employ this information in forensic and burial research to better understand the events surrounding an individual's death.

In this study, fifteen sheep hindlimbs were traumatized to produce a transverse or a spiral fracture and then the legs were cremated. Radiography was employed to record each phase of the experiment. The cremation temperatures ranged from 450-900°C.

The result of the analysis was a procedure to examine cremated bone for evidence of precremation trauma. The six step procedure includes: in situ observation and photography; reconstruction of the bone; analysis of heat-induced fractures; analysis of traumatic fractures; observation of the impact point; observation of congealed fluids and x-ray comparison. The five types of identifiable heat-induced fractures are the longitudinal, curved transverse, straight transverse, patina, and delamination fractures. By eliminating fractures produced by heat, characteristic fracture patterns produced by tension, compression and shear dynamic forces can be investigated. While transverse traumatic fractures produced in these

experiments were easily identified, the spiral fractures could be confused with the longitudinal heat-induced fractures. The detection of the point of impact, in the form of flake removal, is positive evidence for a fracture resulting from blunt force trauma prior to cremation.

There is evidence provided by this study to conclude that precremation trauma is identifiable. Further research is required to establish the histological basis for the difference in fracture propagation in ductile (normal) and brittle (cremated) bone tissue.

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TABLE OF CONTENTS

Page

ABSTRACT v

ACKNOWLEDGEMENTS vii

LIST OF TABLES x

LIST OF FIGURES xi

LIST OF PLATES xii

CHAPTER ONE: INTRODUCTION 1

- 1.1 Forensic Anthropology-Applied Physical Anthropology 1
  - 1.1.1 Role of the forensic anthropologist 2
- 1.2 Types of Material 4
- 1.3 Cremated bone - Discussion of the Material 6
- 1.4 Hypothesis 8

CHAPTER TWO: LITERATURE REVIEW 15

- 2.1 Cremation Literature 15
  - 2.1.1 Visual analysis 16
  - 2.1.2 Demographic analysis 22
  - 2.1.3 Medico-legal cases 29
- 2.2 Trauma 32
  - 2.2.1 Accidental origin 32
  - 2.2.2 Intentional origin 35
- 2.3 Bone Structure 38
  - 2.3.1 Bone matrix 39
  - 2.3.2 Effect of trauma upon bone 48
  - 2.3.3 Fracture propagation in unburned bone 54
  - 2.3.4 Histological effects of heat on bone fracture 57
- 2.4 Summary 62

CHAPTER THREE: METHODOLOGY 64

- 3.1 Material 64
- 3.2 Recording Method 66
- 3.3 Cremation Furnace 68
- 3.4 Fractures Observed in the Experiments 71
- 3.5 Procedure 72
- 3.6 Blind Test 74

CHAPTER FOUR: DISCUSSION AND RESULTS 75

- 4.1 Recovery 75
  - 4.1.1 Collection practices and in situ observation 75
- 4.2 Reconstruction 77
- 4.3 Identification of Heat-Induced Fractures 79
- 4.4 Identification of Traumatic Fractures 85
- 4.5 Further Characteristics 92
  - 4.5.1 Appearance on the x-ray 92
  - 4.5.2 Adhesion of soft tissue 93
  - 4.5.3 Impact Point 93
- 4.6 Blind Test 95
- 4.7 Implications and Limitations 102
- 4.8 Summary 103

CHAPTER FIVE: CONCLUSIONS 105

REFERENCES 115

PLATES 127

LIST OF TABLES

Table	Description	Page
1	Description of the Cremation	7
2	Age Categories used by Various Researchers	25
3	Force Types and Resultant Fractures	52
4	Stages in the Process of Cremation	60
5	Vital Statistics for the Sheep Experiments	66
6	Characteristics of Heat-Induced Fractures	84
7	Fracture Identification Procedure	104

LIST OF FIGURES

Figure	Description	Page
1a	Woven bone tissue	41
1b	Cancellous bone tissue	41
1c	Compact bone tissue	42
2	Stress/Strain relationships in bone biomechanics	50
3	Fracture injuries	56
4	Temperature fluctuations I	70
5	Heat-induced fractures	82
6	Anterior and posterior views of the blind test	98
7	Temperature fluctuations II	101

LIST OF PLATES

Plate	Description	Page
1a	Fire-asane furnace	128
1b	The first method	128
2a	The second method	129
2b	Contraction of the muscle tissue	129
3a	The transverse traumatic fracture	130
3b	Reconstruction of specimen #150L	130
4a	The longitudinal HI fracture	131
4b	A longitudinal HI fracture	131
5a	Curved transverse HI (thumbnail) fractures	132
5b	A spiral traumatic fracture	132
6a	Curved transverse HI fracture	133
6b	The curved transverse HI fractures	133
7a	Tibia of #538R	134
7b	X-ray of tibia #538R	134
8a	The patina fracture	135
8b	The delamination fracture	135
9a	Close-up of the delamination	136
9b	Delamination	136
10a	The transverse traumatic fracture	137
10b	The transverse traumatic fracture	137
11a	A comparison of the transverse fracture margins	138

Plate	Description	Page
11b	A spiral traumatic fracture	138
12a	The 'punched in' impact point	139
12b	A reconstructed spiral traumatic fracture	139
13a	Closeup of the reconstruction of #213R	140
13b	Post-cremation radiograph of #213R	140
14a	X-rays of #150R (post-cremation and post-trauma)	141
14b	Crystallized fluids	141
15a	A depressed flake	142
15b	Reconstructed blind test specimen #285R	142

CHAPTER ONE

INTRODUCTION

1.1 Forensic Anthropology-Applied Physical Anthropology

We are in an era of accelerated travel, frequent resettlement, and conflict. All these factors increase the difficulty, in certain circumstances, of the identification of deceased persons. One may well ask how this situation is possible, as it is also an age of DNA fingerprinting, communications satellites, personal information data banks, and the removal of political barriers to communication. However, the fact that people continue to die in mass disasters, air crashes, homicides, political conflicts, house fires, and automobile accidents, to name a few situations, necessitates the presence of specialists trained in the identification of partially or totally skeletonized remains, representing fragmented, complete, or multiple individuals. In cases such as these, soft tissue evidence normally used to identify human remains is usually inadequate for visual identification; for instance, fingerprints may be absent, DNA may be decomposed, and skeletal fragmentation will complicate the identification. Because of the nature of the surviving material, it has become beneficial to engage the services of various individuals specially trained in skeletal interpretation.

The comparative osteologist or physical anthropologist is one professional with such capabilities. The physical anthropologist, traditionally associated with museum or university laboratories, analyzes our ancestral origins and the variability observed between groups of people (Snow, 1982). This education has prepared the physical anthropologist for the study of skeletal remains. Gathering information concerning age, sex, stature, and ancestry, as well as the interpretation of disease processes, occupational indicators, and genetic anomalies, is within the expertise of the physical anthropologist (Kerley, 1980; Lundy, 1986).

This knowledge may be applied to medico-legal work to the advantage of both communities. Forensic anthropologists (physical anthropologists) may assist the pathologist by employing techniques developed on skeletal populations to aid in identification problems, and in this way strengthen the physical profile of the deceased. The applied physical anthropologist (here titled the forensic anthropologist) must draw on training in the four-field discipline of anthropology (Kerley, 1980; Warren, 1978), and must have a working knowledge of the medico-legal system. It is important for the forensic anthropologist to know the limitations of her/his possible contributions as prescribed by the particular medico-legal system. The forensic anthropologist gains from this relationship through the ability to implement methodology generally applied to populations without recorded social records.

1.1.1 Role of the forensic anthropologist

The forensic anthropologist is called in as a consultant, not as an investigator or pathologist. Her or his job is not to solve a crime or to determine cause and manner of death, but rather to accumulate information about the individual(s) from their skeletal remains (Snow, 1982; Stewart, 1979:55-81; Warren, 1978). The information provided by the forensic anthropologist will be used later by the medical examiner or coroner to establish cause and manner of death. The goal of the forensic anthropologist is to provide a phenotypic description which can be used to identify the deceased. This description will include estimations of age, sex, stature, ancestry; and descriptions of skeletal anomalies (occupational markers, disease, and trauma), to be compared with antemortem radiographs and the individual's social history where available.

The forensic anthropologist has been able to establish a niche in the United States Armed Forces. Their role in the identification process is rigidly defined in the job description supplied by the U.S. Armed Forces (cf. Warren, 1978:84-86). The position, goals, and duties of the forensic anthropologist

> ...may be summarized in the form of primary and secondary goals to be held and acted upon by the physical (forensic) anthropologist and his co-workers in the laboratory: a) establish the uniqueness of the remains, that is reduce commingling to zero; b) identify the remains, that is, establish the correct location of the former living individual in the social matrix of his or her family, commmunity and society; c) improve current techniques and develop new methods for more efficiency and reliability in the establishment of the above primary goals; d) increase information in all areas of knowledge relevant to the above primary goals; and e) provide a sound legal basis for the scientific and circumstantial findings (Warren, 1978:86).

These goals are not limited to the forensic anthropologist employed by the army to repatriate war dead, to identify victims of political executions, or to identify accident victims within the Armed Forces. The goals are equally as relevant for the forensic anthropologist employed by the coroner or medical examiner; as ultimately the goals are the same: identification, understanding, advancement, and reliability.

Within Canada, the forensic anthropologist has only recently entered the medico-legal system; and then, only as a consultant. The relationship between the forensic anthropologist and the death investigation facility depends upon the type of system in use in the province or territory. At present, the only provinces with the medical examiner's system are Alberta, Manitoba, and Nova Scotia. The remaining provinces and the two territories have retained the Coroner's system, with coroners appointed by the judicial system. In most medical examiner's systems, the Chief Medical Examiner is a qualified pathologist appointed by the Government to oversee the investigation of sudden deaths (*Fatality Inquiries Act*, Chapter F-6, 1985). Coroners, on the other hand, are often laypersons with no medical background.

The goals of the forensic anthropologist are the same in Canada and the United States. As the pathologists, investigators, and police are educated about forensic anthropology, the forensic anthropologist will presumably play a greater role in the Canadian medico-legal system. This participation may take the form of multiple roles, including: death investigator, forensic anthropologist, and archaeologist. When the situation permits, the forensic anthropologist may be established as a necessary component of the normal forensic team. The habitual inclusion of the forensic anthropologist in the medico-legal system (eg., accepted in the courts as well as within the sudden death investigation team) will be beneficial to the investigation of unattended or suspicious deaths.

1.2 Types of Material

The material to which the forensic anthropologist is referred is usually in one of three conditions: skeletonized, decomposed, or incinerated. Partially or totally skeletonized remains present a problem for the medical examiner/coroner, as the soft tissue is no longer available or useful for identification purposes. The experienced forensic anthropologist can provide information about the individual(s) with respect to the type of material (bone, human or not); the number of individuals (multiple parts); time since death (prehistoric, historic, modern); age; sex; and ancestry. Skeletonized remains may be very fragile, and will often require management unfamiliar to the medical examiner/coroner. Also collection of disarticulated, scattered remains can be accomplished efficiently with excavation techniques derived from archaeology and practiced by the forensic anthropologist. Analysis which would be time-consuming and problematic for the pathologist is welcomed by the forensic anthropologist, who is not generally burdened with a heavy case load.

The second type of remains, which are perhaps better handled by a team composed of a forensic anthropologist, forensic odontologist, and forensic pathologist, are those which are severely decomposed. As soft tissues decompose, identification from facial features, skin markers (tatoos, scars), fingerprints, and serology becomes less possible. If the pathologist can obtain what information is left from the soft tissues, the forensic anthropologist and forensic odontologist can work on the hard tissues. This team approach will result in a more efficient handling of the remains, and therefore the decomposing remains will remain in the medical facility for a shorter time period. The departure of these remains is appreciated by those individuals exposed to them.

One further kind of material the forensic anthropologist can interpret is incinerated bone. Bone exposed to intense heat will fragment and distort in such a manner as to appear to be no longer of value for interpretation. Cremated bone has long been ignored (Gejvall, 1969:468), and still continues to be by some. The forensic anthropologist's close acquaintance with the subtle characteristics of the human skeleton makes him/her a valuable component in the analysis of cremated bone. The forensic anthropologist should have an understanding of the response of bone to heat, and how this will affect the interpretation of the individual characteristics mentioned previously.

The method of collection of fragmented, incinerated bone is extremely important, as much of the information about the relationship of bone fragments can be lost if haphazard, hurried, or careless collection is made. The forensic anthropologist, by applying careful archaeological recovery methods, may be able to provide the death investigation team with far more information than if he/she is presented with a bag of jumbled remains. Also, if the remains are collected, contained, and transported carelessly more fragmentation will occur to this fragile material.

1.3 Cremated Bone - Discussion of the Material

When cremated remains arrive at the medical facilty, they may be charred; partially, incompletely, or completely cremated. The charred remains do not pose as difficult a job for analysis, as serologic analysis and often visual identification can be completed. When only portions of the individual's extremities are badly burned and fragmented, there are fewer problems in the identification than if the remaining tissue consists of an amorphous mass containing the torso, organs, and bony tissue (partial cremation). Every stage of cremation may be witnessed (refer to Table 1): the first stage is represented by charred remains containing the internal organs; in the second stage, some soft tissue remains; only bony fragments remain in the third stage; and the fourth stage is characterized by ash.

As bone reaches the third stage, it has usually undergone gross morphological as well as histological change, resulting in a material reminiscent of fresh bone, but without its resilient nature. The organic component is gone, and the crystalline matrix has altered form (Herrmann, 1977b). The change is analagous to that identified in the process of firing pottery (Shipman, *et al.*, 1984). The stages include: dehydration, oxidation, reduction, decomposition, inversion, and fusion. Understanding the nature of these changes is essential for the interpretation of the remains by the forensic anthropologist.

1. charred	internal organs
2. partial	soft tissue
3. incomplete	bone pieces
4. complete	ashes only

Table 1: Description of the cremation (after Eckert *et al.*, 1988)

The discovery of cremated human remains, either prehistoric or modern, has presented researchers with analytical problems pertaining to the determination of the number of individuals represented, age and sex ratios, living stature, race, perimortem condition, nutritional status, and trauma (Krogman, 1943a and 1943b; Wells, 1960). When faced with a possible homicide or a mass disaster, it is of medico-legal importance to obtain as much information about the cremated skeletal remains as possible, in order to identify satisfactorily those involved, to complete criminal investigations, to conclude insurance claims, and to return the remains to grieving families.

1.4 Hypothesis

Incineration appears to be the most thorough method of disposing of a body when foul play results in death. Skeletal trauma would be eliminated along with the body, and therefore could not be used as evidence against the assailant. It would seem logical to assume that a body can be burned easily to ashes, thus eliminating the possibility for identification of the individual and of the trauma; however, this is an incorrect assumption. The extreme temperatures and the duration of cremation are in excess of what is generally found in a house fire or outdoor pyre, even when accelerants are added to raise the fire's temperature.

In a modern crematorium, it requires temperatures of 1600 -1800°F (871°C.-982°C.) for 90 minutes (Eckert, 1981) to reduce a body to fragments and ash, which must later be pulverized. Even in this form of cremation, identifiable fragments remain. A house fire generally burns at 500°C for the first 8-12 minutes; a flashover occurs at 12 minutes at which time the temperature climbs to approximately 780°C over 55 minutes, finally it cools over a 50 minute period (Richards, 1977). The lowest temperature at which the vapours above a combustible material ignite is referred to as the flashpoint; and once flashpoint is achieved there is a sudden spread of flames known as flashover. If accelerants (such as gasoline or methane) are added, the vapours may flashover at a higher temperature, but the temperature will then subside again. Holland (1989) states that a house fire generally burns at less than 800°C. The outdoor wood fire burns at 400-600°C, but requires constant addition of fuel to maintain this temperature. Wood will usually burn around 350°C (Tylecote, 1962; Rowlet *et al.*, 1974). In an aeroplane fire, the fireball temperatures may exceed 1100°C, and cabin temperature may reach 1093°C (Hill, 1986), because of the diesel fuel and onboard accelerants. However, in the latter case, an explosion will often accompany the fire, causing much fragmentation of passengers and the wide-spread scattering of material (Koelmeyer *et al.*, 1982). The duration of the fire will depend upon the circumstances; however, the extended time required for complete incineration is not usually met. Automobiles will burn around 400°C, with the explosion of gasoline producing a fireball with a temperature of 900°C (Hill, 1986). This fireball is not sustained, as the necessary fuel and oxygen are quickly consumed. Therefore, neither intentional nor accidental cremation of a body will usually be complete; and there will be valuable information for the investigator, pathologist, and medical examiner/coroner, if forethought is used in the collection.

The medico-legal implications of establishing whether or not burned bone fragments are human, to whom they belong, and whether the death and disposal was intentional or accidental are clear. As early as 1849, there is record of a need to determine the identity, cause, and manner of death of an individual partially consumed by fire. The case to which reference is made is the Webster-Parkman trial of 1850 (Dilnot, 1928; Sullivan, 1966, 1967, 1971). The individuals involved were Dr. George Parkman (victim) and Professor John Webster (assailant). The events transpired because of a debt incured by Webster to Parkman. Parkman had let the debt continue until he became aware of Webster's attempt to sell the collateral. Upon demanding repayment on November 23, 1849, Parkman subsequently disappeared. Webster was questioned and his office and laboratory were searched, excluding the lavatory. After a tip from the janitor, the police searched the lavatory in Webster's laboratory and located parts of a dismembered body.

Five main segments of tissue were located: 1) the thorax with associated ribs, lungs, scapulae, clavicles, and vertebrae (7th cervical, thoracics and 2 lumbar); 2) the pelvic region including innominates, and lower lumbar, but separated at the thigh; 3) the right thigh; 4) the left thigh; and 5) the left leg. Also located in a small muffle furnace were fragments of burnt right calcaneus, right talus, tibia/fibula, manal phalanges, coronoid process of the jaw, cranium; a tooth, and three blocks of mineral teeth (Bailey, 1972; Dilnot, 1928; Snow, 1982; and Sullivan, 1971). Subsequent analysis by several prominent doctors produced the conclusion that the remains (partly fleshed and incompletely cremated), were those of Dr. G. Parkman. When the case came to trial, the question arose as to the exact cause of death. The court charged Webster with the murder of Parkman by means of stabbing, kicking/beating, striking with a hammer on the head, or by assault with an unknown weapon. Although in the post-trial confession of the defendant, Webster stated that it was a blow to the head from a piece of firewood which had killed Parkman (Sullivan, 1971:183), cause of death was not substantiated by the investigation. The testimony of two doctors is of interest in this matter. Dr. J. Wyman testified that:

> there were some fractures (*in the skull bones*), which had the appearance of being made before calcining. Before calcining, the animal matter adheres; there is a greater disposition to splinter, and to angular forms rather than to crumble. (Dilnot, 1928:65, italics are mine)

and a second well known witness, Oliver Wendell Holmes, stated that:

> the fracture of the bone after calcination depends upon the degree of calcination. Bones may be calcined so as to easily crumble; but calcined partially, they will split, break outward, or

> inward, and direct across, and in almost any direction.... but could not say that it (*the skull*) was fractured during life. (Dilnot, 1928:127)

This case has been presented not only because the partially incinerated remains were identified, but particularly to note that knowledge pertaining to the fracturing of bone exposed to heat was not well understood. As will be shown in Chapter Two, the situation has changed only fractionally. The ability to distinguish heat fractures from traumatic fractures is still nonexistent.

In 1932, Dr. H. Merkel published an article in which he suggests that it is possible to identify a blow or bullet hole in cremated bone. He cites E.V. Hoffmann's 1885 work, in which it was stated that a smooth blow and/or cut marks could be identified on cremated cranial bones. However, there is no evidence presented to support this assumption.

A more recent incident of interest involved the identification of ten individuals in a railway disaster outside of Hinton, Alberta, in February, 1986 (Foisey, 1986). This civil disaster resulted when a freight train carrying sulphur, grain, and culvert piping collided with a VIA Rail passenger train. The collision resulted in a fire which was fueled by the grain, diesel fuel (ignites at +500°C, Hill, 1986), and sulphur. The fire burned for over 48 hours. As a result of this intense heat, the victims involved experienced a range of cremation, from charred to incomplete incineration (refer to Table 1). Many of the victims were trapped within the wreckage, while others were pulled away from the burning areas. The victims were identified using a variety of anthropological techniques. For age determination pubic symphyseal changes, tooth eruption, epiphyseal fusion, and degenerative changes were used. Sex determination was based on a combination of ischial size, shape of the sciatic notch, cranial bone thickness, and bone size. Other factors used to distinguish the victims were genetic anomalies and association with soft tissue remains (Beattie, 1986).

It is possible that much of the fragmentation of the incompletely cremated individuals could have occurred prior to the fire as a direct result of the collision. Trauma, resulting from flying projectiles (such as seats), may have produced traumatic fractures, which would potentially impede escape. All individuals were identified by a team of forensic scientists (pathologist, odontologist, anthropologists, radiologist, and investigating officers). As a result of this incident, and later observation of the wreckage and bone fragments, the question arose as to how much trauma the victims experienced prior to the fire. Some individuals were not recovered from the area where they had last been seen, and it is assumed that a certain amount of disturbance occurred at the moment of impact. Precremation trauma should be identifiable; but as a result of the lack of understanding about the visual representation of traumatic fractures in cremated bone, this trauma could not be documented.

A final example which is important to the discussion at hand is the reference made by W. G. Eckert and colleagues (1988) to the presence of an identifiable traumatic fracture in cremated remains. The case involved the disposal of a woman's body in a funeral crematorium. The victim's husband had apparently attempted to incinerate her in a "direct-flame, diesel-fueled, forced air oven". Although the oven could produce an ambient temperature of 1350-1500°F, which could cremate remains in three hours, there was still bone in a trap beneath the oven, and a can of bone fragments and associated muscle tissue were located. The body had not been placed in the oven correctly; and as one of the jets was not working, the body burned unevenly. The authors described the presence of a traumatic fracture; however, it is not clear how this fact was established. They state that,

> There was a fracture of the iliac crest from a shearing type of blunt trauma possibly caused by a spadelike shovel. It was not evident whether these injuries occurred before death or afterward (Eckert *et al.*, 1988:199-200).

Consultation with the anthropologist involved in the investigation did not clarify how the trauma was identified, or whether there was any suggestion of when the trauma occurred. The bone in question, the ilium, is embedded in a large muscle mass; and therefore may have been protected for a longer period of time, thus facilitating the identification of the trauma. More specifically, the ilium was unburned. Unfortunately, the investigating forensic anthropologist was, at this time, unable to provide information to substantiate the assumption that the bone was not severely affected by the cremation. It is unfortunate that the bone in question was not illustrated in the article, as this presentation would have benefited other forensic anthropologists investigating cremated bone trauma.

Upon consideration of the foregoing, it became evident that research into the area of cremated remains would be valuable to the medico-legal community. The interpretation of this often severely deformed material is worthwhile, because air crashes, car explosions, house fires, and foul play will continue to supply the medical community with cremated individuals who will require indentification and documentation of injuries.

This project was designed in order to begin to investigate the nature of trauma in cremated bone. Until present the literature, both from the anthropological and medical community, has not been directed toward the examination of traumatic fractures in cremated bone. Therefore, the following thesis will test the hypothesis that precremation traumatic fractures can be distinguished from heat-induced fractures in cremated bone. The demonstration of this hypothesis would allow the forensic anthropologist to interpret injury in cremated individuals.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cremation Literature

Before beginning a study on the presence of traumatic fractures in cremated bone, it is necessary to review what information is available in the current literature. An understanding of the approaches used in the interpretation of cremated bone, which include examination of the visual characteristics, demographic methodology, and implementation of methodology in actual case studies, is important and is covered in the first section. When identifying trauma, one must have a concept of the kind of trauma to be expected; therefore the second section will review the common types of skeletal trauma expected in homicides, air crashes, and auto crashes. The final section will review scme of the pertinent information regarding the nature of bone matrix, its response to stress, and finally the information available about the microstructural response which bone has to heat. With an understanding of the above, one can then proceed to test the previously presented hypothesis that trauma-induced fracture patterns can be distinguished from heat-induced patterns.

The majority of research is based in North America, and North and Central Europe. There is an emphasis in European studies on the use of modern human materials for research, although nonhuman and archaeological material are used. This research concentrates on understanding the effects of heat on the interpretation of age, sex, stature, and ancestry (cf. Böhmer, 1932; Bonucci and Graziani, 1975; Dijkstra, 1938; Dokládal, 1962, 1969, 1970, 1971; Dufkova, 1985; Gejvall, 1969; Grimm and

Theis, 1952; Grupe and Herrmann, 1983; Herrmann, 1970, 1972, 1973a, 1976, 1977a, 1977b, 1980; Hummel and Schutkowski, 1986a, 1986b; Kühl, 1986; Lepkowski and Wachholtz, 1903; Malinowski and Porawski, 1969; Mühler, 1964; Piontek, 1975; Rösing, 1977; Schutkowski and Hummel, 1987; Van Vark, 1970, 1974, 1975; Wahl, 1982, 1983; and Wahl and Henke, 1980). In North America, the emphasis has been on descriptive analysis of the bone tissue when exposed to heat. This research has generally involved the use of non-human bone or archaeological bones (Baby, 1954; Binford, 1963; Bradtmiller and Buikstra, 1984; Buikstra and Swegle, 1989; Forbes, 1941; Shipman *et al.*, 1984; Spence, 1967; Thurman and Willmore, 1980; Webb and Snow, 1945; and Wells, 1960). In recent years, there has been a change in the emphasis of research (cf. Bradtmiller and Buikstra, 1984; Holland, 1989). A third source of research comes from the medico-legal community. Those involved in the direct interpretation of burned human remains have been able to supply the practical evidence of successful interpretation of remains, based upon current methodology and experience (cf. Bass, 1984; Burns, 1988; Clark, 1986; Dokládal, 1969; Dunlop, 1978; Eckert *et al.*, 1988; Gebhardt, 1923; Heglar, 1984; Johanson and Saldeen, 1969; Krogman, 1943b; Maples, 1988; Merkel, 1932; Richards, 1977; and Wilson and Massey, 1987).

2.1.1 Visual analysis

There has been a continuing interest in understanding burned remains for over 140 years, andseveral reviews of the scope of this work have been published. For a review of the older literature, Lepkowski and Wachholz (1903) and Thieme (1937, 1938) are good sources. To obtain information on the advances since 1938, the papers by Grimm (1961) and

Müller (1964), and several articles by Herrmann (1972, 1973, and 1980) are excellent starting points. However, in order to fill in the details of cremation research, it is necessary to look closer at the various participants and what they thought important to study.

Immediately upon the examination of cremated bone fragments, it is apparent that a variety of colours may be observed. The significance of the change in the colour of the cremated bone has been studied by various researchers. The colours commonly represented range from brown to grey-blue, black, grey-white, and chalk-white; and other colours less frequently noted are green, yellow, pink, and red (Dunlop, 1978). The general concensus is that these various colours represent the temperature attained by the bone and the length of exposure (Bonucci and Graziani, 1969; Heglar, 1984; and Shipman *et al.*, 1984); and that these colours are a reflection of the organic and inorganic material associated with the body's response to increased temperatures. The brown colouration is associated with haemoglobin and/or soil discolouration (Gejvall, 1969; Lisowski, 1968), while the black results from carbonization of the bone burned in an oxygen starved state (Herrmann, 1970). The grey-blue and grey result as the organic components of bone are pyrolized (Dokládal, 1969, 1970; Shipman *et al.*, 1984). The white colour of calcination is the final stage, as the china-like texture of the bone represents the complete loss of the organic portion of the bone and the fusion of the bone salts. The latter group of colours (green, yellow, pink, and red) have been attributed to the presence of copper/bronze/iron in the surrounding environment, zinc in coffin linings, systemic copper, and the madder plant, respectively (Dunlop, 1978; Gejvall, 1969; Lisowski, 1968). Not much has been done with these observations other than to suggest the type of cremation practice which was utilized (cf.

Gejvall, 1969 and Lisowski, 1968) and the temperatures which may have been achieved (Bonucci and Graziani, 1969; Shipman *et al.*, 1984). A variety of colours may be present on a single bone fragment (personal observation), and the entire range of colours may be present in a single cremation; therefore interpretations of the temperature of the fire or the position of the body should be conservative.

Equally evident when one observes burnt bone is the change in morphology. The bones have undergone changes in length and width. Researchers have attempted to quantify the amount of change in spongy and compact bone, because any shrinkage undergone by the bone may influence conclusions drawn regarding the age, sex, or stature of the individual. In an early study by Malinowski and Porawski (1969), the measurements of human skulls and long bones taken before cremation were compared with those taken afterwards. The differences were recorded in millimeters; for example, the diameter of the radius decreased 0.7 mm., while the head of the radius decreased 1.2 mm. (1969:396).

Through time more sophisticated analyses of bone shrinkage have been completed. Dokládal (1971) cremated one half of each of the five cadavers, and preserved the second half. From measurements taken on the unburned side and comparison with the cremated side of the same individual, he established a shrinkage of 5-12%.

By heating 20 mm x 5 mm femoral sections of compact bone at temperatures ranging from 150°C-1200°C, Herrmann (1976, 1977a, 1977b) recognized three phases of shrinkage. The first, from 150°C-300°C and the second, from 750°C-800°C, resulted in 1-2% shrinkage. The final stage occurred between 1000°C-1200°C, and resulted in 14-18% shrinkage. He concluded that the shrinkage was dependent upon four criteria: 1) distribution of bone types (compacta, spongiosa, and lamellar), 2) temperature of exposure, 3) mineral content of bone, and 4) aspects of the mineral content of bone tissue. He found a relationship between sex and the amount of shrinkage: males have a higher percentage of bone mineral and more shrinkage, while the reverse is true for females. The implication of this conclusion is that bone's from males will shrink more and be more gracile in appearance than the female counterparts. The tendency to sex males as females will arise; however, the 1-2% shrinkage expected up to 800°C should not significantly impair the conclusions.

In a further study using spongy bone, Grupe and Herrmann (1983) record a 12% reduction in various measurements. In compact bone, Bradtmiller and Buikstra (1984) observed a 5% shrinkage up to 600°C; and Buikstra and Swegle (1989) suggest a correction factor of 0-10%. In temperatures up to 1000°C, Hummel and Schutkowski (1986b) record a 5% shrinkage in the proximo-distal length of the compact bone, but a 27% reduction in the cross-sectional diameter. The identification technique which uses wall thickness for sex determination may, therefore, be adversely affected.

A recent study by Holland (1989) claims that the cranial base is expected to shrink by 1- 2.25%; but he notes that above 800°C this figure may be an underestimate, as measurements were more difficult to make on the severely calcined bone. The studies generally agree that the expected shrinkage in cremated bone up to temperatures of 800°C would not be significant in the interpretation of the bone. More studies are required for a better understanding of cancellous bone (such as femoral head, and cranial bones).

Even if shrinkage is of little significance, warpage and deformation will affect the visual appearance of the bone. Kühl (1986) has identified deformation which results from weight upon the bone tissue while it is in the plastic stage of strain. This deformation does not occur during life and is not pathological, but may appear, for example, in the vertebral arches or in the head of the joints in cremated bone. This is not to say that pathologies may not be present and identifiable; but on the contrary, many have noted the presence of dental pathologies, arthritic change, healed fractures, periostitis, and growth lines in cremated bones (Baby, 1954; Herrmann, 1970; Kühl, 1980; Lisowski, 1968; Malinowski and Porowski, 1969; Merbs, 1967; and Rösing, 1977).

Initially, it is customary to determine whether the bone is animal or human in origin, and the number of individuals represented; and to provide a description of the surviving fragments. These tasks must be done prior to any analysis of age, sex, stature, and race (Gejvall, 1969; Lisowski, 1968; Malinowski and Porawski, 1969; Stewart, 1979; and Wells, 1960). Dokládal (1969), Spence (1967), and Wells (1960) supply extensive lists of skeletal parts which have survived most frequently in archaeological urn burial and in modern crematory studies. It is apparent that the denser bones and those well embedded in muscle tissue are more frequently found.

One final aspect of the visual description of cremated bone which has received much attention is the presence of various heat-induced fractures. The nature of these fractures in bone which is burned fleshed, defleshed (green), or dry (degreased) is controversial. The earliest descriptions are those of W.M. Krogman (1943b) in a case involving a possible amputation.

He claimed that:

> Wherever soft tissue surrounding a bone are scant or thin, the bone shows sharp, clear-cut heat fractures (looking somewhat like the patina of age on an old painting), charring, calcination and splintering; where the bone is deeply embedded in muscle... the action of heat on a bone is to produce a molten condition, characteristic of fusion by heat. (1943b:13)

He applied this theory again in 1945 for W.M. Webb and C.E. Snow on cremated bone from the Adena and Hopewell cultures. He was asked to determine if the individuals were burned in the flesh or after skeletonization. The "patina" cracks were used to indicate dry (defleshed) bone, and the presence of endosteum to indicate bone burned with flesh attached. He notes a difficulty in distinguishing bone which was fleshed and that which was recently defleshed; this is also the case with several other researchers (cf. Binford, 1963; Buikstra and Swegle, 1989).

Baby (1954) concluded that dry bone does not show any warping, but shows superficial checking, longitudinal fractures, and transverse splintering. Binford (1963) supported Baby's assertions; and he observed the presence of straight transverse cracks in dry bone, versus curved, transverse cracking in fleshed bone (green); these latter cracks represent the so-called thumbnail fractures often observed on long bones. In the experiments on human, bovid, and canine bone, Buikstra and Swegle (1989) do not support the previous conclusions. They noted warping in both green (fleshed) and dry bone; and felt that "the presence of deep transverse cracks clearly is not sufficient evidence for identifying fleshed cremations" (1989:256). They found it easier to distinguish fleshed (green) bone from dry bone based on colour.

The differentiation of fleshed and green (or recently defleshed) bone has been even more problematic. Thurman and Willmore (1980-81) attempted to distinguish fleshed human humeri from green human humeri. They concluded that fleshed cremations characteristically presented serrated, transverse fractures and diagonal cracking and warping, while green bone had serrated fractures at the epiphyses only, parallel-sided fractures in the shaft, and less pronounced warping. These characteristics are not discontinuous, and therefore are subject to individual interpretation.

One other individual, Lisowski (1968), has described the fractures observed on incinerated bone; but he does not indicate the pre-incineration condition. He noted the cracking of teeth, and the splitting of the compact bone along straight or elliptical trajectories; the twisting or bending of bone; and the separation of the internal and external tables in cranial bone.

There does not seem to be a satisfactory method available yet to differentiate the condition of bone prior to incineration based on gross visual observation of fractures. The methods suggested are subjective, and lack any clear standardization.

2.1.2 Demographic analysis

The main purpose for studying cremated bone is to develop a conception of the individual(s) which the bones represent. In order to develop a demographic outline of an archaeological population or an individual identity of a suspicious or unattended death, it is essential to determine the age, sex, stature, and possible ancestry of the individual(s) under study.

Age estimation of cremated remains has mimicked the development of aging techniques on non-cremated bones. In 1934, C. Krumbein published an article in which he analyzed archaeological urn graves. His analysis was based upon comparison of size, and he was not able to break down age categories into more than "matur" and "infans".

Cranial sutures have been used most consistently to estimate age, although as early as 1968 they were considered unreliable by those studying cremated bone (Lisowski, 1968). Most early researchers suggest that ecto- or endocranial suture closure may be used (Dzierzykray-Rogalski, 1967; Gejvall, 1969; Malinowski and Porawski, 1969; Merbs, 1967; C. Müller, 1964; Schäfer, 1961; and Wells, 1960), but there are researchers (Buikstra and Goldstein, 1973; Doklădal, 1969; Hummel and Schutkowski, 1986a, 1986b; Lisowski, 1968; Piontek, 1975; and Rösing, 1977), both early and recent, who have stated the limited use of sutures for age estimation of cremated bone.

More reliable estimates of age may be achieved by observing a combination of epiphyseal fusion, tooth eruption and abrasion, long bone length, pubic symphyseal changes, rib end changes, cranial bone thickness, tooth density (Dufková, 1985), osteon remodelling, and degenerative diseases (Bradtmiller and Buikstra, 1984; Malinowski and Porawski, 1969; Piontek, 1975; and Rösing, 1977). Herrmann (1970) noted that observations made upon cremated bone were subject to the amount of shrinkage and/or warping experienced by the bone. For example, long bone lengths may be misinterpreted due to the proximo-distal shrinkage, estimated at 5% (Hummel and Schutkowski, 1986b).

When the methodology for estimating age is determined, there is still a problem in determining the number of reliable age categories which may be used. As few as two and as many as eleven categories (refer to Table 2) have been used to categorize the age of the individual (Krumbein, 1934, and Herrmann, 1970 respectively). The majority of researchers, however, use six categories.

The accuracy of the age estimation is reliant upon the method's precision, and the degree of bone destruction and distortion. Dokládal (1969) felt that he had a 60%+ correct diagnosis of age on a control group; his worst group was the 45-65 year olds (adultus). In an archaeological sample, Merbs (1967) was able to estimate age on only 36% of the adults; he gives no estimate of the percentage on non-adults.

One should always be conservative when estimating age on cremated remains, as the material is frequently incomplete. This fact, and the general range of variation found in non-cremated bone age estimates, should make the researcher more conservative. This author finds the eleven stage category unrealistic; and would suggest the use of a system which emphasized the younger age groups and only gross divisions for the adult groups: perhaps Rösing's (1977) categories.

As with age determination, sex determination of cremated bone has progressed as the methodology for sex determination of non-cremated bone has developed. Morphological and metric analyses have all been tried, in order to get a better estimate of the individual's sex. Some researchers were apparently unaware of the possible inaccuracies arising due to deformation of the bone exposed to high temperatures (cf. Dzierzykray-Rogalski, 1967; Grimm and Theis, 1952; Krumbein, 1932; and Schäfer, 1961).

Throughout the literature, the use of the morphological characteristics of the cranium and mandible have predominated. The morphology of the female skull is perceived as more gracile in nature than

Krumbein,34	Dokládal, 69	Wells, 1960	Rösing,1977 Thieme, 1970 Lisowski, 68	Gejvall,1969	Herrmann, 1970
Infans	Infans I	Child	Infans I	Foetus	Infans I
Matur	Infans II	Adolescent	Infans II	Newborn	Early-Mid Juvenile
	Infans III	Young Adult	Juvenis	Child	L juv.- E.Adult
	Juvenis	Full Adult	Adult	Adolescent	Early-Mid Adult
		Middle Adult	Matur	Young Adult	Midadult
		Adult	Senile	Matur	Mid-Late Adult
				Senile	Late Adult
					Adult (at least)
					Adult
					L.Adult-E.Matur
					Early Matur

Table 2: Age categories used by Various Researchers

that of males, and therefore several features may be compared. The degree of muscle attachment development, size of mastoid process, the shape of the supraorbital margin, the size of the external occipital protuberance, the thickness of cranial bones, the mandibular angle, and the shape of the mental protuberance are all characteristics, used in combination when possible, to establish the sex of the individual(s) (Dzierykray-Rogalski, 1967; Lisowski, 1968; Merbs, 1967; Müller, 1964; Piontek, 1975; and Thieme, 1970).

The analysis of these traits is dependent upon two main factors: 1) survival and 2) degree of shrinkage. The skull is fragmented into its many components when exposed to high temperatures (Dokládal, 1967, 1970). The facial bones rarely survive intact; but fortunately the denser portions, such as the pars petrosa, occipital ridge, supraorbital margin, portions of the mandible, and parts of the flat bones (parietal, frontal, and occipital) may survive. This method of analysis is subjective, and the researcher requires some knowledge about the normal variation to be expected in the expression of the traits within the population under study. Shrinkage may confuse the researcher into the misclassification of males as females (Herrmann 1976, 1977a).

Morphological analyses of postcranial remains is more complex. Although the pelvis is considered the best area to estimate sex (Stewart, 1979:104), it is frequently fragmented by fire (Dokládal, 1969). The degree of destruction is dependent upon the temperature of the fire, and will determine the value of the pelvis for interpretation. When present, the greater sciatic notch, ilium, and possibly pelvic shape may be used to suggest sex. The cortical thickness of the long bones has been used more frequently (Müller, 1964; Schäfer, 1961; and Thieme, 1970), but with care. The size of the femoral, humeral, and radial heads has been used; but the degree of shrinkage experienced by the spongy bone exposed to intense heat (up to 12%: Grupe and Herrmann, 1983) makes these estimates extremely uncertain.

Another approach to sex determination is through discriminant analysis. G.N. Van Vark (1970) claims that cremation does not reduce the validity of metric observations of bone. He feels the discriminatory values need only be lowered slightly. Rösing (1977) suggests that a greater percentage of remains may be sexed, if discriminant analyses are used.

The pars petrosa has been examined by Wahl and Henke (1980) and Schutkowski (1983) to establish its value in sex discrimination. Wahl and Henke used five variables and two discriminant functions. One function uses three variables and the second uses five. They found that a shrinkage of 10% had little effect on the interpretations. A recent study completed by Holland (1989) suggests that the cranial base does not shrink more than 2.25% in temperatures under 800°C. He feels that this amount of shrinkage does not hinder metric analyses.

A final approach to determining the sex of an individual is through the association of gender-related grave goods (Lisowski, 1968; Müller, 1964; and Wells, 1960). The ability to determine the sex of a juvenile or child is not possible through morphological or metric analysis, but may be inferred from grave goods.

It can be seen that the determination of sex is reliant upon the researchers' knowledge of the various methods used in non-cremated bone.

It is necessary to be aware of the expected heat shrinkage for each bone type (compact and cancellous), and to know the effects of warpage upon the trait.

The ability to reconstruct an individual's live stature from fragmentary remains is fraught with problems. If reconstruction of the long bone(s) can be made, then measurements can be taken and used in such a stature regression such as that designed by Trotter and Gleser (1952). However, if fragmentation is extreme, and only small portions of the long bone can be reconstructed, it is necessary to turn to the various methods suggested for stature estimation from fragmentary remains (Müller, 1935; Müller, 1958; Steele and McKern, 1969; Steele, 1970; and Strzalko *et al.*, 1972). These methods have been used by researchers working with cremated remains (cf. Lisowski, 1968; Malinowski and Porawski, 1969; Piontek, 1975; and Rösing, 1977), but with the knowledge that there is a large and often compiled margin for error.

The methods proposed by Müller (1958) and Strzalko and colleagues (1972) depend upon the diameter of the radial, humeral, or femoral head. The conclusions must account for the shrinkage of the spongy bone (~12%) located in the epiphyses.

There seems to be no satisfactory answer to the issue of stature estimation. The use of vertebrae for estimation is not feasible, as survival of the vertebra is poor (Doklådal, 1969). If the long bone has been protected by a muscle mass (eg., femur), there may exist a greater chance of obtaining a near complete bone for analysis; otherwise it may not be possible to determine stature.

Another aspect of individualization which is all but impossible to establish from severely cremated remains is race or ancestry (Lisowski, 1968; Malinowski and Porawski, 1969; Müller, 1964; Schäfer, 1961; and

Rösing, 1977). One individual has attempted to reconstruct the orbit for the purpose of race determination. Gladykowska-Rzeczycka (1965) describes a case in which it was possible to observe the shape of the orbit after reconstruction, but this case has not been followed by further research and testing. The determination of race should only be considered in instances, in which there is substantial facial or cranial material and complete long bones.

To conclude this cremation literature review, it is necessary to examine some actual case studies, in which the aforementioned procedures have been put to the test in forensic situations. This is an important step, as once individuals are identified, the researcher's conclusions can be compared to fact; not the case when analyzing most archaeological remains.

2.1.3 Medico-legal Cases

Early forensic cases have emphasized the use of the dentition to establish a positive identification. Böhmer (1932) discusses the important role of dentition in five cases. In one case, the examination of soft and hard tissues established that the victim was a female aged 15-30 years. There was a suggestion from the remaining soft tissue that cause of death was attributed to strangulation and not the fire. The size, shape, and eruption status of the teeth aided in the age and sex determination.

Merkel's article in 1932 examines several instances of charred remains. These cases were analyzed for cause of death as well. The examination of carbon monoxide in the system is advocated, in order to determine the state of the individual before death. He also described the presence of trauma upon calcined cranial bones; however, he realizes that these may have been the result of heat-induced fractures.

Not until 1943 is there a review of evidence for the analysis of calcined bony remains to establish an identity. W.M. Krogman was called upon to analyze the remains of two separate cases. The first remains were the charred human remains from a forest fire (Krogman, 1943a, 1949:74). The completeness of the individual allowed for the examination of skull shape, pelvic traits, teeth, sutures, and long bones (radius) to present a picture of a male, Caucasian, aged 45-50. The particular individual was not identified at that time, so the analysis could not be verified. The second case examined by Krogman (1943b) required the determination that a leg bone was shortened by fire and not amputated. By observing the molten state of the compact bone and by providing no evidence for atrophy, he was able to conclude the leg was burned away.

Johanson and Saldeen (1969) present three cases in which dental and skeletal evidence, together with cooperation between various agencies, resulted in positive identifications. By comparison of ante and post-mortem records, the identifications were verified. This is one of the earliest instances located in the literature which records the use of the reconstruction of bony tissue for analysis. The left femur and an ulna were used to estimate age and sex in one case. In another case skeletal pathologies and x-ray comparison were used to support the identification.

From the remains recovered in a garbage pit, Heglar (1984) was able to determine the presence of the incinerated remains of a juvenile and two adults plus a child. Multiple representation of parts, cranial sutures, epiphyseal fusion, muscularity, size, orbital margins, mandibular shape, tooth root and type (deciduous or permanent) were used to estimate age, sex, and number of individuals represented. With the use of antemortem x-rays, the identities were verified. The accused confessed to the murders and disposal of the bodies. Heglar also used the pubic symphysis and long bone cortical thickness to determine the age of one charred individual. An antemortem chest x-ray was used for positive identification.

The use of x-rays for verification of a suggested identity is seen again in the case described by Dufková (1985). The body of a severely burned individual was recovered; and a description of the individual as being a female, aged 12-16 (<20), was provided by evidence from the pelvis, teeth (eruption and density), and epiphyses. There was no stature estimate made, but tibial and fibular bone was compared to antemortem x-rays to provide twelve points of comparison. Also an x-ray of the left elbow showed evidence of a healed fracture.

A final case study presented in 1988 by Eckert and his colleagues has been referred to previously, and it involved the disposal of the victim in a crematory oven. The bony remains and dried blood were sufficient to establish the identity of a Caucasian female in her early thirties. DNA testing proved the blood belonged to the victim and not to a dog or to another individual, as suggested by the accused. Unfortunately, there is no mention of the methodology used by the physical anthropologist to establish age, sex, and race.

As shown here by these few examples, it is often unclear as to the precise methodology used by the medico-legal community to obtain the necessary information to establish the identity of burned (incinerated) remains. It is unclear whether there is due consideration of the effects of shrinkage upon the analysis. Because positive identifications are frequently based on comparative radiographs, which were located through the initial description, it is often considered unnecessary to record the methods used to obtain the description. This shortcoming in the medico-legal reporting could be remedied by adding a few explanatory notes. With this addition, it would provide researchers with some valuable feedback regarding the validity of their work.

2.2 Trauma

The present study is aimed at the interpretation of traumatic fractures, and therefore it is important to be aware of the types and locations of the hard tissue injury in various violent deaths. The airways and roadways have become crowded and potentially lethal places. Because these modes of transportation are fairly standardized in form, we can expect to see some regularity in the type of injury expected from each. When it is the investigator's intention to identify trauma in cremated remains, it is important to have a conception of what types of injuries should be expected. For example, there is little value in spending time looking for cut marks on bone joints after an explosion causing dismemberment. This section will explore hard tissue injury incidences in accidental and intentional injury.

2.2.1 Accidental origin

Air crashes present the victim with the dual problem of survival of the crash and escape from the aircraft. The latter problem is often the more difficult (Salomone *et al.*, 1987). If the passenger is incapacitated, due to limb injury or some other non-fatal trauma, the chance of leaving the aircraft in the very limited time (estimated at 135 seconds: Hill, 1986), is substantially reduced; and the chance of death by inhalation of carbon monoxide or other poisonous gases, and heat exposure from post-crash fire is greatly increased. This situation is described by Salomone and colleagues (1987):

> The victims who remained inside the fuselage and died from smoke inhalation and fire suffered fractures in their extremities nearly half as often as those in the trauma group (*those dying of blunt force trauma*). (Salomone *et al.*, 1987:1409)

In short, remaining within the fuselage can mean dying of the side effects of the fire, because trauma to the limbs prevents escape.

Depending upon the nature of the crash, one may expect to identify certain types of injury patterns. There are injuries associated with the horizontal movement of the aircraft; these are known as flexion forces. The common hard tissue damage resulting from flexion forces are cranio-facial fractures, distal radial and ulnal fractures, rib and spinal fractures, and distal tibial and fibular fractures. Vertical movement produces vertical force; and may result typically in basal skull fractures; pelvic, femoral, and lower spinal fractures. Explosion or separation of parts of the fuselage may result in dismemberment of the body (Koelmeyer *et al.*, 1982). In-air fires and ground fires may result in burns of varying degree.

Hill (1986) notes that two-thirds of crash victims receive head injuries. Salomone and colleagues (1987) recorded 132 fractures in the 1985 Galaxy flight 203 aircrash in Reno, Nevada, which took 69 lives. Fractures represented 60% of the injuries recorded. Of this 60%, cranial fractures were most common (34%), followed by chest fractures (28%), lower limb (24%), upper limb (13%), and pelvic fractures (<1%). Limb fractures and cranial fractures may result from the confined space available for the passenger to move within the aircraft (Hill, 1986); and occur on impact, because the body moves rapidly forwards and backwards and/or up and down.

The second form of crash, the automobile crash, produces injuries in accordance with the shape of the vehicle and the distribution of occupants (driver, front passenger, or rear passenger) (Grattan *et al*, 1973). The steering wheel, gear box, glove compartment, window, dash, and seat back, and non-belted occupants of the car, all provide ample sources for potential injury. Incineration in automobiles is less common than in air disasters, for example, Tonge *et al.* (1977) recorded a 1.2% incidence in automobile accidents. Hill (1986) recorded a 47.5% incidence in air crashes, and Salomone and associates (1987) recorded that 60% of the deaths in air crashes were associated with fire. Incineration in automobiles is, nevertheless, within the top three causes of burn fatalities (Parks *et al.*, 1989).

The skull is the most vulnerable portion of the body in motor vehicle accidents. In the 1004 accidents analyzed by Tonge and his colleagues (1977) some cranial fractures occurred in 48.3%; however, 75.6% of the victims suffered fractures to the various limbs. The most affected limb was the femur/hip complex (23.3%). The spinal column also appears to be frequently fractured (23.9%), with the cervical vertebrae being most commonly affected (16.7%). Horowitz and colleagues (1987) estimate that 46-48% of the occupants receive leg fractures (note these data apply to individuals without seat-belts). For purposes of this present investigation, soft tissue injuries are not considered, as they would not be available for study in incinerated remains. However, when faced with severely charred remains, soft tissue damage will obviously be relevant in the interpretation of the pre-fire condition of the individual.

It is possible, then, to suggest from the above that studying limb fractures and cranial fractures in cremated bone is of value. There is also the possibility that incapacitation from trauma sustained in the accident, either air or auto, may be a significant factor in an individual's inability to escape from the scene and the ensuing fire.

2.2.2 Intentional origin

Another extremely important goal of the forensic anthropologist investigating cremated remains is identifying signs of foul play. Depending upon the weapon and the location of the injury, identifiable fracture patterns exist. In the following section skeletal injury produced by blunt injuries to the skull, gunshot wounds of the skull, stab wounds to the chest, and skeletal damage produced by dismemberment will be examined.

An important concept to understand is how the anthropologist uses the information gained from observing traumatic injury. This information is used to *suggest* the possible manner of death. There is rarely concrete evidence for determining cause of death from the skeletal remains; but the manner of death may be determined as homicide, suicide, accident, or unknown (Sauer, 1984). These conclusions, however, remain the privilege of the Coroner or Medical Examiner.

Blunt trauma to the skull does not often provide useful information as to the manner of death. The linear fracture produced by a single blow from a blunt object is one example (Krogman, 1949) as the blow can be intentional or unintentional. Krogman goes on to state that,

> ....multiple and/or patterned or comminuted fractures are almost invariably due to intentional assault. (Krogman, 1949:46-47)

Large blunt weapons (eg., clubs, wood, stone) produce crushing injuries. In the skull, the blow may result in a depressed fracture or more specifically a pond fracture (Merbs, 1989). The pond fracture is recognized as a depressed fracture encircled by a fracture or series of circular fractures (Merbs, 1989). The circular fracture occurs because the skull does not rebound from the inbending produced by the object. Gurdjian and colleagues (1950) carried out a number of impact tests, and described the various fracture patterns expected with blows to various regions of the head. They also discussed the analysis of direction or order of blows. One interesting fact mentioned is the inability of one fracture to extend across the path of a previously formed fracture. In general, the fractures originate at a point distant from the impact and radiate toward it.

The blow from a rapidly moving blunt object will produce the pond fracture, while the slow-moving object results in linear fractures associated with the depressed fracture. A sharp, slowly moving object may provide the researcher with the pattern of the object in a depressed fracture. One form of blunt trauma associated with self-defense is the parry or Monteggia's fracture. This fracture occurs in the forearm, usually the ulna, when the forearm is raised to ward off a blow to the face (Merbs, 1989; Ortner and Putschar, 1985:57).

A sharp object will produce a more defined hole or puncture in the bone (regardless of location: femur, skull etc.) (Brothwell, 1965:122; Gurdjian *et al.*, 1950; and Stewart, 1979:78). When an axe, knife, ice pick etc. is used by the assailant(s), it may be possible to identify linear cutmarks or depressed areas upon the bone (Krogman, 1949:48; Stewart, 1979:78). The depressed area may even reproduce the shape of the weapon. Stabbing injuries are commonly identified as cuts on the ribs (Sauer, 1984) or on the surface of the vertebrae (Krogman, 1949:48; Ortner and Putschar, 1985:73). An axe may produce a slicing effect, which results in the removal of a bone fragment (Brothwell, 1965:125; Merbs, 1989; and Ortner and Putschar, 1985:71).

An important and relatively common injury, often witnessed today, is the bullet wound. The bullet, depending upon its velocity, will produce distinctive damage. The cranial vault is perforated, and the pressure may result in a bursting fracture (Gurdjian *et al.*, 1950). The low velocity bullet may be deflected, resulting in chipping or depressed defects (Krogman, 1949:46). The high velocity bullet, however, will produce a characteristic entrance and exit wound. The entrance is described as small; and smooth edged or punched on the external table of the skull, but bevelled or cratered on the inner table. The exit wound is larger; and rough, with the cratered area on the external surface of the bone. There are radiating fractures associated with the exit wound (Krogman, 1949:47; Stewart, 1979:77). Bullets may enter any area of the body and lodge within a bone or leave tiny fragments of lead in their path. Shotgun pellets are frequently embedded in bone and their presence is identified radiographically (Stewart, 1979:77). While the bullet is a relatively non-destructive force, producing small holes and fractures; the shotgun or rifle may produce vast amounts of bony damage.

A final form of trauma which is worth looking for on cremated remains is intentional dismemberment. Intentional dismemberment will usually occur after death, unlike accidental dismemberment in air crashes. The process of segmenting the body is usually attempted through joint areas. The tools used may vary from a knife to a power saw. The saw will leave distinctly roughened surfaces and defleshing may leave cutmarks upon the bones (Brothwell, 1965:128; Merbs, 1989; and Symes, *et al.*, 1990).

Manual strangulation, identified by the fractured greater cornu of the hyoid and/or fracture of the thyroid cartilage (Stewart, 1979:79), is less likely to be identified in cremated remains, as the hyoid and associated cartilages are easily destroyed in more complete cremations.

Amputations, scalping, trephanning, and poisonings are going to be less frequently identified in forensic cases than the foregoing injuries. Old amputations, as noted by Krogman (1943a), are identifiable by the presence of a bony cap over the marrow cavity, and by disuse atrophy. The problem of identifying perimortem amputations in cremated material is escalated, as it may be impossible to distinguish this feature from fire trauma. Scalping results in a bone tissue response (Ortner and Putschar, 1985:91), but again perimortem scalping would be suggested only by cutmarks upon the cranium. Trephanning, or cranial bone removal, is of little importance here and the interested researcher is directed to Brothwell (1965:128) or Ortner and Putschar (1985:92). It has been suggested that poisons may be identified in the bone matrix (Krogman, 1949:59). The value of searching for poisons in cremated bone assumes that these compounds (Pb, arsenic, cyanide etc.) survive high temperatures. Herrmann and Grupe (1988) concluded that higher temperatures do not lead to a significant loss of various minerals (Zn, Sr, Ba, Mg, Ca, P), with the exception of lead (Pb).

2.3 Bone Structure

The last section of this chapter will describe normal and cremated bone structure. When attempting to interpret the fractures observed in cremated bone, it is necessary to have some basic understanding of the nature of bone matrix, how this complex tissue/organ is expected to respond to stress, and finally what the microscopic affect of heat is on the bone matrix. The literature on the first two aspects is vast, and therefore only a basic review of the concepts is attempted here. The latter component has been dealt with only recently via scanning electron microscopy, microradiography, and x-ray diffraction.

The description of bone tissue and how this tissue reacts to the stress produced by blunt force trauma, and histologically by heat are the topics of this final section of the literature review. Bone tissue is very complex, and is still not completely understood (Ortner and Putschar, 1985:25). As bone behaves both as a tissue and an organ, it must be investigated within these parameters. Its organization at the gross and histological levels is directly dependent upon its function as a specialized connective tissue, and as an organ storing myeloid tissue (bone marrow), which produces monocytes and some lymphocytes (Leeson *et al.*, 1985:160; Ortner and Putschar, 1985:24). There is no attempt to review all the literature on these subjects, but rather to provide some information to prepare the reader for the analysis of the experiments proposed to test the hypothesis that trauma-induced fracture can be distinguished from heat-induced fracture.

2.3.1 Bone matrix

Macroscopically, bone is a rigid but flexible and strong material. The form of a specific bone is dependent upon its location in the body, and the various stresses applied by the actions of the associated muscles. Fossae, ridges, and vascular impression on a smooth, dense cortical bone (with the exception of the vertebrae) can be found on the external surfaces. The internal surface, generally, has visible bony trabeculae. The presence of this bone type diminishes towards the midshaft on the long bones and short bones, and is replaced by myeloid tissue. The irregular bones, such as the innominates, scapulae, carpals, tarsals, and clavicles, have varying amounts of spongy bone surrounded by a layer of cortical bone. The cranium consists of two layers of periosteal bone between which spongy bone (diplöe) is sandwiched.

Three types of bone have been referred to previously; these require further description and the addition of two more types. Five distinct types of bone tissue exist in the body: 1) cortical (compact), 2) cancellous (spongy), 3) woven (prenatal compact), and 4) periosteal and 5) endosteal (lamellar) bone.

In order to understand the differences between these types of bone tissue, it is necessary to view the bone at the microscopic level. Woven bone is the first form of bone to be produced (see figure 1a), either at birth or after injury. This bone is composed of an irregular meshwork of fibers in which there are no distinct lamellae (circumferential layers). This type of bone provides a "scaffold" for later remodelling into more organized bone tissue.

Once woven bone is produced, then structural remodelling can occur. The characteristic appearance of cortical bone (see Figure 1c) is the result of this remodelling. Blood vessels tunnel through the bony matrix. They supply nutrients to the organic components of the bone. As new bone is produced, it is organized in concentric lamellae around the blood vessel situated in a canal, now referred to as the Haversian canal. The cells producing the osteoid (bone protein) become entrapped in the inorganic matrix; and because of the need for nutrients, they must maintain a connection with the Haversian canal through channels known as canaliculi. The whole process produces the structural unit of bone: the

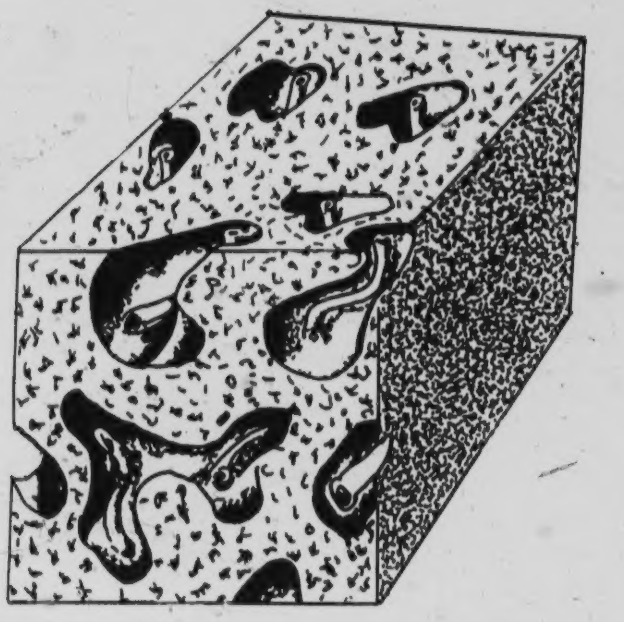


Figure 1a: Woven bone tissue: is not yet remodelled into Haversian systems.

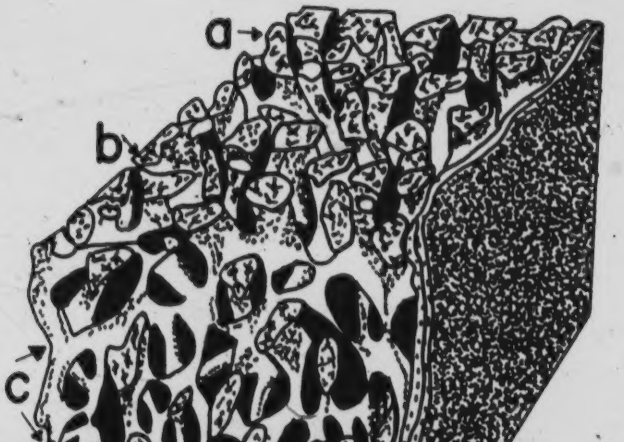


Figure 1b: Cancellous bone tissue:a) canaliculi, b) lacunae, c) trabeculae. Modified from Leeson *et al.*, 1985

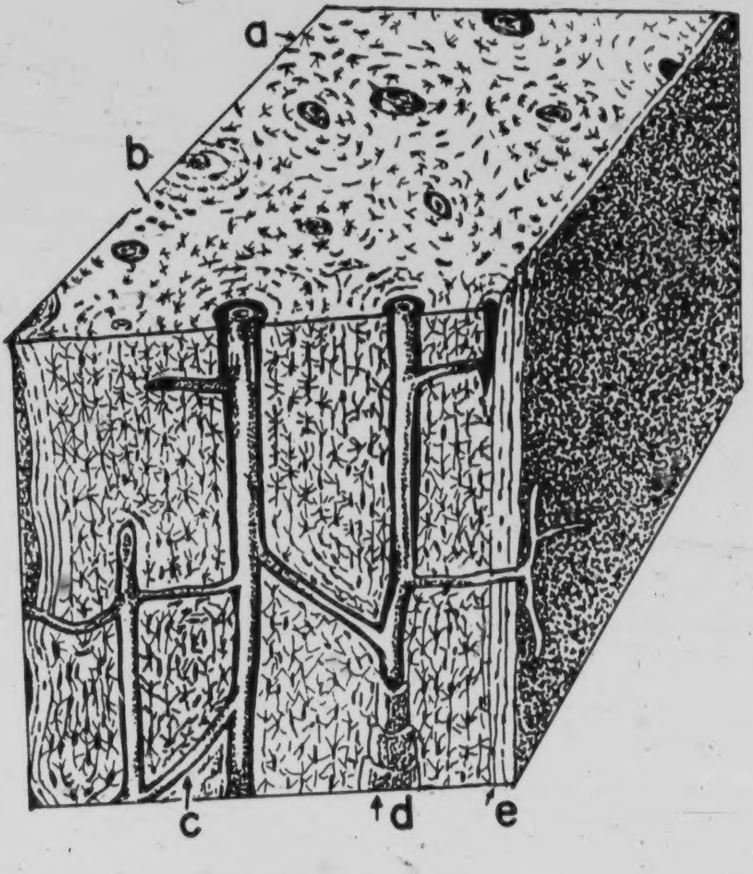


Figure 1c: Compact bone tissue: a) canaliculi, b) lacunae, c) Volkmann's canals, d) Haversian canals, and e) lamellae. The inner lamellae form the endosteum, while the outer circular lamellae form the periosteum. Modified from Leeson *et al.*, 1985

osteon. The osteon consists of the Haversian canal, concentric lamellae, lacunae (housing the cell) and canaliculi. The outer ring of the osteon is a layer of modified matrix; this zone is called the cement line (Evans, 1973:80; Johnson, 1985).

The process of remodelling (removal of primary bone and replacement by new osteons) leaves behind fragments of old osteons. These fragments of osteons are known as the interstitial lamellae. In a cross section of cortical bone, it is possible to identify new osteons and the interstitial lamellae.

On the outer edges of the cortical bone, the lamellae abandon the need to form around the blood vessels, because of the proximity to the marrow cavity or external vascularization. The result is the formation of layers of lamellar bone without the Haversian systems. These layers of bone form the inner (endosteal) and outer (periosteal) margins of the cortical bone. The cellular function of these bone types is slightly modified. Endosteal bone, situated on the inner perimeter of the cortical bone, contains cells which function osteogenically and haemopoietically. The outer perimeter, the periosteum, contains osteoprogenitor cells. Therefore, the periosteal lamellar bone is stimulated by injury to produce osteoblasts (bone forming cells) to initiate repair (Leeson *et al.*, 1985:146).

Nerves and blood vessels enter the bone in a variety of loci, but one main foramen can usually be located. This blood and nerve supply anastomoses into longitudinal Haversian canals and transverse Volkmann's canals. In this manner, the dense cortical bone is sustained.

A variation on the cortical bone is the cancellous or spongy bone (see Figure 1b). The main feature which exists to distinguish these forms is the absence of Haversian canals in the latter. The primary lamellar bone, which is formed after the woven bone, is tunnelled through and the cavities are filled by marrow. The result is a structure not unlike the support for a suspension bridge. There are series of trabeculae which anastomose to produce a scaffold-like appearance. Spongy bone is located at the epiphyses of long bones, within the irregular bones, between the inner and outer tables of cranial bone, and in the vertebral bodies. The arrangement of the trabeculae is thought to respond to the stress applied to the bone (Pope and Outwater, 1972) and can realign if the stress changes (Bouvier, 1985; Steele and Bramblett, 1988:10; and Rogers, 1982b).

Bone, then, is organized into five types which can be distinguished on the basis of their structural (visual) design and their location. To reiterate, 1) woven bone is an irregular meshwork of bone tissue; 2) cortical bone contains a system of anastomosing blood vessels and nerves surrounded by concentric layers of bone matrix, which enclose cells within the lacunae. Because of the constant remodelling of bone, cortical bone tissue contains numerous osteonal fragments, or interstitial lamellae. Surrounding the internal and external periphery of cortical bone are layers of lamellar bone without Haversian systems, the 3) endosteum and 4) periosteum, respectively. Finally, there is 5) spongy bone, which is trabecular, with marrow-filled cavities.

Bone has an inorganic and organic portion. These components act in unison to provide the bone with its characteristics of hardness, strength, and resilience. Bone is an anisotropic material: one whose parts differ in response to stress, but when acting together become stronger than each of the individual components (Evans, 1973:10; Johnson, 1985; Reilly and Burstein, 1974). The organic portion of bone provides the bone with strength and resilience (Leeson *et al.*, 1985:131; Roger, 1982a), while the inorganic portion supplies the hardness: the tensile versus the compressive strengths, respectively. More on this relationship will be presented once the nature of these components is understood.

The organic component of bone is the living portion which requires nutrients to survive. The cells, fibers, and ground substance of bone matrix compose the organic portion. The organic component constitutes approximately 35% of the bone mass (Leeson *et al.*, 1985:131). Of this, some 90% is collagen, a fibrous protein. The rest constitutes the bone cells and ground substance (mucopolysaccharides, lipoproteins, amino acids, and water) (McLean and Urist, 1961:26; Ortner and Putschar, 1985:24).

The cells found in bone tissue are those which produce, maintain, and destroy bone matrix; and produce collagen fibres. Osteoprogenitor cells (mesenchymal cells) located in endosteal and periosteal bone produce three types of bone cells. The osteoblast, a single nucleus cell, produces the bone protein or osteoid, which is later mineralized. The osteoblast is thought to be associated with the central canal, and to initial mineralization (Frost, 1966). It is also located in the endosteal and periosteal lamellae. Osteoblasts may be produced by reticular cells located in the myeloid tissue (McLean and Urist, 1961:11). The entrapped osteoblast is known as the osteocyte. This cell has a single nucleus, and functions in bone maintainence and in secondary mineralization. As mentioned previously, these cells must maintain a connection with the vascular supply, by cytoplasmic extensions extending from the cell through canaliculi to other osteocytes, or to the central canal in the case of the innermost lamellae. The job of bone resorption is completed by the osteoclast, a large multinucleated cell. The osteoclast can be found in close proximity to the osteoblast in the circumferential lamellae and is often located within depressions in the bone matrix, known as Howship's lacunae.

One other cell type located in the bone tissue is the fibroblast. This cell is necessary for the production of collagen fibers. The fibroblast synthesizes the triple helix procollagen within the cell. Procollagen is modified once it leaves the cell to become tropocollagen, the structural unit of collagen (Darnell *et al.*, 1986:973). The tropocollagen molecules link together in a staggered orientation, much like a brick wall, to form fibrils, with an overlap between molecules of approximately 70 µm. This overlap produces the characteristic banding viewed in electronmicrographs of collagen, which repeat every 64 µm. The tropocollagen fibrils are organized into collagen fibres at the next level. The collagen fibres have a high tensile strength, which results because of the linkage between the tropocollagen fibrils (Darnell *et al.*, 1986:178). The type of collagen found within bone tissue is Type I. Type I collagen is defined as having two chains of ∂1(I) type polypeptide chains and one chain of ∂2(I) type.

The collagen fibres compose some 90% of the organic matrix, and are therefore important constituents of bone tissue. Their function in the process of mineralization of bone is not fully understood (Posner and Beebe, 1975); however, they are thought to act as a template for the mineral ions (McLean and Urist, 1961:35; Ortner and Putschar, 1985:25; Pope and Outwater, 1972). Collagen fibres are oriented parallel to the longitudinal axis of the bone in Haversian (osteonal) bone; but in lamellar bone, they tend to align perpendicular to each other (Carlström and Glas, 1959; Johnson, 1985; Ortner and Putschar, 1985:12). Carando *et al.*, (1989) present a theory which suggests that the alignment of collagen is dependent upon the structural requirements. Collagen oriented longitudinally would be found preferentially in areas resisting tensile stresses, while transversely-oriented collagen fibres would be resistent to 'buckling' or compressive stresses.

The ground substance of bone tissue consists of highly polymerized mucopolysaccharides. These include chondroitin sulfates (A, B, and C) and hyaluronic acid (McLean and Urist, 1961:27).

The larger portion (65%) of bone matrix consists of an apatite mineral. This mineral is thought to be similar to a crystalline compound known as hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$] (McConnell, 1962; Posner and Beebe, 1975; Sasaki *et al.*, 1989). Calcium phosphate constitutes the greater percentage of mineral salt present (~85%); but calcium carbonate, calcium fluoride and magnesium fluoride can also be found (Leeson *et al.*, 1985:131; McLean and Urist, 1961:31; Ortner and Putschar, 1985:25). J. F. Osborn and H. Newesely (1980) conclude that 30% of the mineral salts in bone tissue are amorphous calcium phosphate, and a little less than 70% is crystalline hydroxyapatite.

The crystal structure of hydroxyapatite is described as hexagonal (Carlström and Glas, 1959; McLean and Urist, 1961:33) and rod or prism-like in shape (Sasaki *et al.*, 1989). The first authors estimate a crystal size of 400Å x 40Å, while the second estimate a length of 500Å, width of 250Å and a thickness of 85Å. Sasaki and colleagues (1989) record a crystal size of 25-75Å x 400-1200Å. The apatite mineral is thought to be closely associated with the collagen fibres. The length of the crystal may be related to the periodicity of the tropocollagen; this would correspond to the 64 µm banding (Ornter and Putschar, 1985:25)

Water is associated closely with the inorganic portion of bone tissue. The water is attracted to the crystalline structure in two ways. The first and most easily removed water is the physisorbed water, loosely adsorbed to the crystal surface. Water is also bonded to the apatite mineral, and is known as chemisorbed water (Civjan *et al.*, 1971; Posner and Beebe, 1975; Rootare and Craig, 1977). It is thought to be of importance in the strength of bone tissue (Evans, 1973:55; Pope and Outwater, 1972). This is of interest, as one of the effects of heating of bone is the removal of water.

2.3.2 Effects of trauma upon bone

Before a discussion of the traumatic response of bone tissue can begin, it is necessary to set the stage. An understanding of the terminology is essential, as terms such as stress, strain, modulus of elasticity, force, fracture, compression and tension are intimately associated with the issue of trauma. These terms are often misunderstood and misapplied. In this section "normal" non-cremated bone tissue is discussed, with heat-affected bone left to the last.

In this paper, reference is made to heat-induced fractures and traumatic fractures. This terminology is somewhat confusing, as a fracture of either type is traumatic to the bone tissue, meaning that the bone has been forced to change conformation because of a change in the environment. This change in shape is defined as a stress upon the bone tissue (Rogers, 1982a). However, in this case there are two types of stress (trauma). Heat-induced fractures are the result of internal, evenly distributed, constant pressure static loads; while the traumatic fracture referred to in this study is the result of a dynamic load, a concentrated blunt blow to the bone, which produces the fracture. Therefore, for clarity of the distinction of the two types of fractures under examination, the first type is called the heat-induced fracture resulting from static internal stress

(Johnson, 1985); while the second type is the traumatic fracture, and results from a dynamic load (stress) to the bone.

While stress is the force which changes the bone, strain is a description of the change (Rogers, 1982a). These two concepts can best be understood diagramatically (see Figure 2). As the stress increases so does the strain until this strain produces in the bone a point of yielding which ultimately results in failure or fracture of the bone. The fracture is a mechanical failure of the bone tissue, which occurs at the failure point (Johnson, 1985).

Before the bone reaches the yield point, it may return to its original condition, if the stress is removed; this development is known as elastic deformation. However, once the bone enters the stage of plastic deformation, it can no longer; recover and may fail if stress continues. Rogers (1982a) suggests that the change results because the elastic stage represents the straining of the atoms within the molecule; in contrast to plastic deformation which is the slippage between the molecules. The slope of the zone of elastic deformation is the modulus of elasticity, and measures the stiffness of the material (brittleness).

The fracture which results is dependent upon the type of force applied; therefore it is necessary to have an understanding about the possible types of force available and the type of fracture produced. There are three pure forces (Evans, 1973:4): tension, compression, and shearing forces.

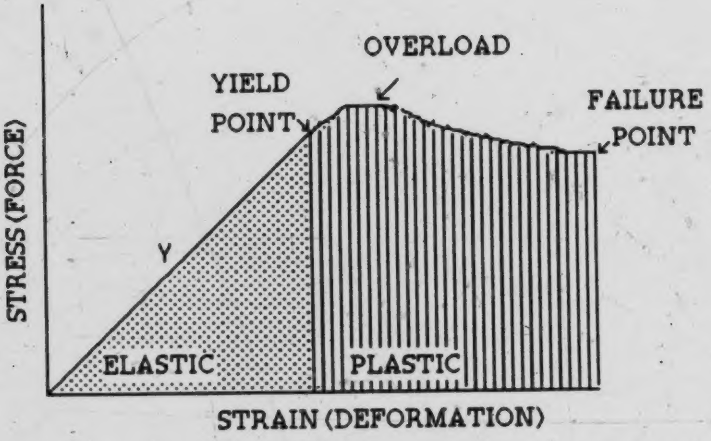


Figure 2: Stress/Strain relatationships in bone biomechanics
Slope of Y= Modulus of Elasticity
Modified from Rodgers, 1982a

Pure tensile forces do not generally act upon living bone (Rogers, 1982a), as this is a force which pulls bone apart. An example of a tension fracture is a fracture of the patella (see Figure 3a), involving the quadriceps muscle and tibial tendon. These structures encase the patella; and are pulled superiorly and inferiorly, such that the action results in a dislocation of the knee and a tension fracture of the patella (Alms, 1961; Ortner and Putschar, 1985:56; and Rogers, 1982a). The fracture which results is transverse (refer to Table 3). Hydroxyapatite is thought to respond poorly to tensile stress (Rogers, 1982a), therefore if there is a loss of the organic portion of the bone, the bone loses its tensile strength, becomes brittle (Johnson, 1985), and is prone to tension fractures.

The action of pushing together areas of the bone produces the compression fracture (Alms, 1961). The classic compression fracture is the failure or collapse of a vertebral body (see Figure 3b), which occurs, for example, when an individual has a vertical fall and lands upon her/his.

feet or results after the bone loss associated with osteoporosis (Ortner and Putschar, 1985:57). This load is applied concentrically upon the long axis of the bone (Johnson, 1985). The compression fracture is slightly oblique to the long axis (Rogers, 1982a). Often compression and tension work together: in this way it is possible to produce a bending fracture.

Two types of bending fracture occur. The force may bend a bone with no axial loading and this will produce a simple bending fracture (Alms, 1961; Johnson, 1985; and Rogers, 1982a). This stress places the concave side in compression, perpendicular to the long axis of the bone; and the convex side in tension. The transverse fracture is initiated on the side in tension. A fracture of this type is the parry fracture (see Figure 3c), which results in a transverse fracture to the radius and/or ulna, when the forearm is raised to "parry" a blow (Merbs, 1989).

The second bending fracture results when the bone is under axial compression (eccentrically applied), and then receives a dynamic load perpendicular to the long axis of the bone which bends the bone. Once again, the concave side of the bone is under compression, while the convex side is under tension. A small triangular bone is often found on the compressed side. This fragment is produced by a shearing force, and is known as a butterfly fragment (see Figure 3d). An example of this fracture type is found in the tibia when it is hit by a car bumper, a shock which may involve the tibia and fibula.

The third pure force is shear stress (Evans, 1973:4). The shearing force is produced when the upper zone of an object, such as bone, is forced in a direction opposite to the lower section (Rogers, 1982b). The shearing force, without axial loading, will produce a transverse to oblique fracture. This feature is seen in the Colle's fracture (see Figure 3e), in which a fall

Force	Fracture Type	Example injury
Tension	transverse	patellar fracture
Pure Compression	oblique	concertina vertebral fracture
Compression/Tension with no axial loading	transverse	parry fracture
Compression/Tension with axial loading	transverse-oblique (butterfly fx.)	tibial bumper fracture
Shear without axial loading	transverse or oblique	Colle's fracture
Shear with axial loading	spiral	skier's ankle injury

Table 3: Force Types and Resultant Fractures

onto an outstretched hand produces an oblique fracture on the distal radius. The distal end is sheared off posteriorly (Merbs, 1989; Ortner and Putschar, 1985:59).

The second type of shear fracture is produced with a shear force and axial loading. The result of this stress is the rotational or twisting fracture known as the spiral fracture (see Figure 3f). This type of fracture is most likely to occur to a skier falling with their bindings attached (Ortner and Putschar, 1985:57). The failure takes an helical path along the bone at an angle of 45° to the long axis (Johnson, 1985). By definition,

> the fracture outline curves as a helix, partial helix, or combination of helixes, around the shaft, and the fracture occurs in the part of the shaft enclosing marrow and not in trabecular bone tissue (Haynes, 1983:104).

The six most common combinations of stress have been described, but nothing is that simple. The type of fracture which results from a force is dependent upon the severity of the load, its location, and the internal environment of the bone. In order to describe a fracture, it is necessary to identify whether the fracture is open or closed; complete or incomplete; spiral, transverse, oblique; comminuted or not; its location; and whether or not it is pathological or not (Ralston, 1967).

A fracture is described as open when the bone pierces through the skin and muscle. The closed fracture, on the other hand, does not break the skin surface, but may do serious muscular damage (Oestern and Tscherne, 1984).

The complete failure of bone tissue is called a fracture, while the incomplete failure is an infarction (Ortner and Putschar, 1985:55). Finally, a fracture may be simple or comminuted: these mean the fracture has occurred cleanly, with no fragmentation (eg., simple fracture); or with the production of multiple fragments (eg., comminuted fracture)(Alms, 1961; Ortner and Putschar, 1985:55). Secondary fractures in comminuted fractures may be produced by the pressure of the bone on bone (Alms, 1961; Sadek-Kooros, 1972).

In summary, it is possible for a bone to experience stress which will deform the bone by straining it. The amount of deformation is dependent upon the modulus of elasticity of the bone and the extent of the stress. When the bone can no longer withstand the stress it fails or fractures. There are six main types of forces which can act upon bone: tension, compression, compression/tension without axial loading, compression/tension with axial loading, shear without axial loading, and shear with axial loading. The resultant fracture is dependent upon the force of the load, its location, and the micro-environment of the bone.

2.3.3 Fracture propagation in unburned bone

When a fracture is viewed at the gross visual level, a break is observed through the cortical and lamellar bone, in the case of the long bones; and through the trabecular and cortical bone in irregular bones and epiphyses. The characteristics of this break can be described, as shown in the foregoing; but what is happening within the tissue? It is interesting to observe what disruption occurs at the histological level as well.

Bone tissue is a structural unit and the final design is determined by the stresses applied during growth (Rogers, 1982b). It is possible to view the bone tissue as a unit whose parts function together to provide a stable structure. When there is a disruption (strain) on any of the individual elements, then the entire structure is weakened.

It is vital to the understanding of the propagation of fractures to recall the structure of bone tissue, including the lamellae, Haversian systems, and the organic and inorganic components. Because of the presence of these structurally unique types of bone tissue, it is possible to echo the words of Schaffler and Burr, who state that:

> differences in organization of lamellar bone in spongy and compact bone, results in different mechanical properties for them, therefore they should be regarded functionally as distinct structural materials (Schaffler and Burr, 1988:16).

Each of these types of bone has the ability to absorb a certain amount of stress. Cancellous bone with its high porosity (>70%) has a low modulus of elasticity (Schaffler and Burr, 1988) and by definition it has a low stiffness.

Flexibility is therefore high in spongy bone. This feature is important for the absorption of forces through the epiphyses (head and neck) of long bones. In contrast, compact bone has a higher modulus of elasticity (less flexible), and its period of plastic deformation is reduced (Chamay, 1969). Compact bone strength is greatly influenced by its state of mineralization. It is a tissue designed to withstand bending forces, and in this function the periosteal and endosteal lamellar bone is aptly suited (Evans, 1973:83). A greater tensile strength is obtained when there are a few large osteons (Evans, 1973:287), thus increasing the percentage of collagen fibres. There is an important relationship between the ratio of primary and secondary osteons and bone strength (Rogers, 1982b). The higher percentage of secondary osteons in older bone produces a weaker bone tissue.

Fractures follow the line of least resistence. This is considered to be the cement line surrounding the osteon which is less mineralized (Evans, 1973:290; Johnson, 1985). The connection between the lamellae is also weak and a fracture will easily travel along this border (Evans, 1973:289; Pierkarski, 1970; and Pope and Outwater, 1972;). Features such as lacunae, canaliculi, and blood vessels may alter the fracture's path; and thereby increase the hardness of the tissue (Pierkarski, 1970); however, it is equally likely that the force is sufficient to cause the fracture to traverse these features (Pope and Outwater, 1972). These authors claim that weak areas between lamellae act as a crack-stopping mechanism in transverse fractures. At the ultramicroscopic levels, the collagen fibres become important components in fracture propagation. The microcrack is seen to travel over and between collagen fibres, but may fracture the hydroxyapatite crystal (Pope and Outwater, 1972). If this is the case, the removal of the

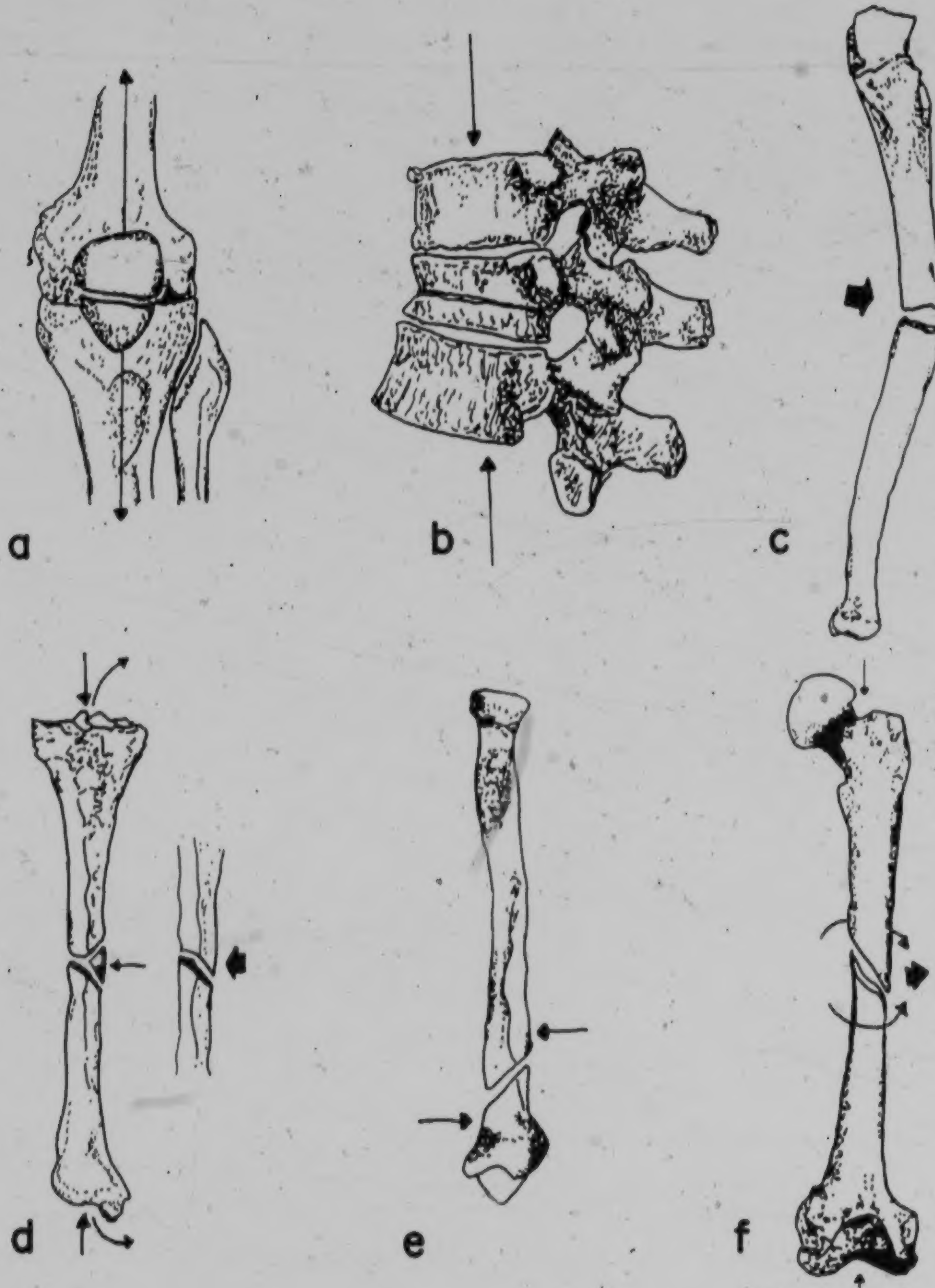


Figure 3: Fracture injuries: a) pure tension: patellar fracture, b) pure compression: concertina vertebra, c) compression/tension without axial loading: parry fracture, d) compression/tension with axial loading: tibial bumper fracture, e) shear without axial loading: Colle's fracture, and f) shear with axial loading: spiral fracture.

organic portion of the tissue, the hydroxyapatite, which is a brittle material, would render the bone susceptible to severe fracturing.

2.3.4 Histological effects of heat on bone fracture

The earliest work located which attempts to describe the histological changes found in cremated bone is that of Forbes (1941). His study resulted from a medico-legal case in which he was required to determine whether a burned sample was bone. He supplies us with a description of compact and cancellous tissue exposed to the heat of a bunsen burner. The general observations were made with decalcified thin sections under normal light microscopy. For compact bone, he describes an initial prominence of the canaliculi which disappear as the lamellae become coarse and granular. The lacuna are described as changing from flat and distorted to mere hazy outlines. The lamellae gradually disappear, leaving a uniformly granular matrix with Haversian canals throughout. The Haversian systems decreased in size, but the Haversian canals increased in diameter and filled with debris. He notes the presence of cracks, which are irregular in width; they tend to travel along the periphery of the Haversian system to join with other cracks. Regarding the origin of the cracks, he states:

> it is difficult to be certain whether these fissures are entirely due to the action of heat (Forbes, 1941:59).

The cancellous bone undergoes similar changes, with the exception of those noted for the Haversian systems. Lacunae and lamellar structures eventually disappear, and only a granular matrix remains.

The observations made by Forbes were simplistic, but the basics were described. Studies completed in the last fifteen years have merely filled out the picture. Thermogravimetry has provided us with a description of the process of water and carbonate removal from the tissue, and x-ray diffraction provides data about the conformational changes within the non-organic crystalline matrix. Microradiography allows us to view the shrinkage of the osteons, and scanning electron microscopy has provided an intense magnification (eg.~1000-1500x) of the bone tissue surfaces.

Thermogravimetry research provides evidence for the phases completed by bone tissue as it increases in temperature. The method records the weight changes of the material (Bonucci and Graziani, 1975). Three phases are identified. These relate to the loss of water, pyrolysis of organic components, and the loss of carbonates and crystal fusion (Bonucci and Graziani, 1975; Civjan *et al.*, 1971; Holager, 1970; and Rootare and Craig, 1977). The first stage begins at 105°C, and is constant until 300°C. The water removed at this point is adsorbed or physisorbed water (Rootare and Craig, 1977), and this stage is completed at approximately 500°-600°C (Civjan *et al.*, 1971). In the latter part of this stage, the organic material begins to be lost. The organic substances (mucopolysaccharides, amino-acids, collagen, etc.) are pyrolized by the time a temperature of 600°C is reached (Bonucci and Graziani, 1977; Civjan *et al.*, 1971). This loss represents the second stage of weight loss. The loss of collagen is established at 500-600°C, because at this point the bone tissue becomes isotropic; the collagen loses its birefringence in polarized light (Herrmann, 1972). Schultz (1986) argues that birefringence of the bone tissue is still observed at 750°-800°C.

The remaining components of bone, the carbonates and mineral salts, are important participants in the third stage. The third stage witnesses the disappearance of the carbonates ($CaCO_3$), and some decomposition of magnesium. Civjan and associates (1971) identified this weight loss at 700°-900°C, but Bonucci and Graziani (1975) place it at 600°-900°C. It is interesting that Holager (1970) identified a similar weight loss at 700°C and 713°C for dentin and enamel, respectively. The hydroxyapatite (HAP) is also affected in the third stage. An argument regarding the nature of the change experienced by the hydroxyapatite exists. Bonucci and Graziani claim that the crystals increase in size, and the ultrastructural change of hydroxyapatite to ß tricalcium phosphate produces the weight loss. Civjan and associates (1971) support this suggestion, but Shipman *et al.* (1984) see no evidence that the crystals undergo a chemical conversion, only an increase in crystal size. Newesely (1988) supports the conclusion that the hydroxyapatite (HAP) alters in structure between 700-1000°C to resemble ß tricalcium phosphate. He attributes this alteration to a coalescence of the crystals. Through x-ray diffraction he records a change in the breadth of the (002) peak, from fraction 1.65 to fraction 1.95. The chemical formulae for hydroxyapatite and ß tricalcium phosphate are $Ca_5(PO_4)_3OH$ and $Ca_3(PO_4)_2$, respectively (Herrmann, 1976).

This process of water loss, carbonate loss, and mineral sintering is compared by Shipman *et al.* (1984) to the changes associated with the production of ceramics. It is worthwhile repeating some of these stages, as they provide us with terminology which is adaptable to this study. The first stage is dehydration. This refers to the breaking of the hydroxyl bonds, and water removal (adsorbed and bound water). The second stage is decomposition, and this stage correlates to the pyrolysis of organic materials.

Dehydration	Water removal (Physisorbed & Chemisorbed)
Decomposition	Removal of organic component
Inversion	Removal of carbonates Conversion of HAP->ß tricalcium phosphate
Fusion	Melting of crystals

Table 4: Stages in the Process of Cremation

Inversion is the third stage, and is identified by the loss of carbonates and crystal conversion. The final stage correlates with the melting of the crystals, and is then the stage of fusion. Table 4 summarizes these points. This sequence will be referred to as the "DDIF process".

Herrmann (1977) states that while bone remains below 700°C, it is incompletely cremated, as organic matter is still present. Shrinkage is estimated at only 1-2%. As major shrinkage of the bone does not occur until 700°-800°C, microradiographs may still be useful in observing bone structure (Bradtmiller and Buikstra, 1984). Herrmann refers to bones exceeding 700°-800°C as complete cremations. The 700°-800°C mark appears to be the "critical point" (Herrmann, 1977), after which microstructural and ultrastructural changes are extreme.

The final method of viewing burned bone is perhaps the most dramatic, the scanning electron microscope (SEM). Through the eye of the SEM, researchers have been able to describe the tissue surface at different temperatures. In this way, the weight loss changes identified by thermogravimetry can be explained by structural changes.

In the first stage of the DDIF process, bubbles form in the external lamellae (Hunger and Leopold, 1978:31); and the bone begins to crack (Hunger and Leopold, 1978:31; Susini *et al.*, 1988). The fine structure of the cortical bone remains visible (Bonucci and Graziani, 1975), with the lacunae expanding and becoming closely packed (Schultz, 1986). Shipman *et al.* (1984) describe the surface as rough up to the 285°C mark, and then as glassy and smooth. Evans (1973:44) notes that the increase in temperature and the decrease in water content causes an increase in microhardness; this decrease in the energy-absorbing capability of the bone ultimately results in the formation of a brittle material.

During the decompositional stage, gross bone structure is still identifiable (Bonucci and Graziani, 1975); but the crystals have increased in size to ~80Å in diameter (Bonucci and Graziani, 1975; Susini *et al.*, 1988). The lacunae are larger, and the edges of the Haversian canals have roughened (Schultz, 1986). Hunger and Leopold (1978:78) identify large diagonal and reticular cracks, and the bubbles have deepened. The smooth glass-like surface described by Shipman *et al.* (1984) has become "frothy and fleecy" in appearance.

In the third stage (inversion), cracks widen; and lamellae are lost as the matrix becomes homogeneous (Hunger and Leopold, 1978:31; Schultz, 1986). It is only at this point where Schultz (1986) observes fissures. The crystals have lost their characteristic hexagonal appearance, and have been replaced by irregular polygonal crystals (Bonucci and Graziani, 1975).

Once fusion begins at 800°C+, osteons appear to infold (Schultz, 1986); and blisters or large oval openings are observed (Hunger and Leopold, 1978:32; Schultz, 1986; and Shipman *et al.*, 1984). The etiology of these blisters is not clear. The lacunae, according to Schultz (1986), are still visible; but gradually disappear by 1100°C. The cracks have crossed between osteons to produce large fissures. The crystals appear large (0.2-0.3 μm side) and irregular (Susini *et al*, 1988). As this stage ends there is a decrease in the rate of shrinkage (Herrmann, 1977b; Schultz, 1986). After this point, there are no observable changes until the bone begins to melt around 1600°C (Schultz, 1986).

It would appear that although each of these researchers have described the picture in their own vernacular, they are describing the DDIF process in much the same manner. It is interesting to reflect back on Forbes' (1941) observations described earlier, and to see how accurate he was with observation only on thin sections with normal light microscopy.

Observations of the nature of heat fractures at a microscopic level do little to increase our understanding of the origin and propagation of the fracture as the current literature is vague in this area. Baud and colleagues (1986) described cracks perpendicular to the periosteal surface and Haversian systems. This description was later expanded by Susini and associates (1988). They felt the fissures originated on the surfaces of canals and/or lacunae, and radiated at right angles. The fissures were thought to radiate at right angles to the collagen fibres, but would not extend beyond the ray of the osteon. Beyond these observations, we know nothing of the route of the fracture in the early stages; for example, does it follow the collagen fibres or lamellae? Are the cement lines important? At what stage does the material act as a brittle and does this development change the movement of the fracture front?

2.4 Summary

With this final section, the literature review is concluded. The information contained within has demonstrated that research on cremation material is multifaceted, including observations on colour and size; gross description of heat fractures; sex, age, and stature determination; and the application of this information in medico-legal situations. The second portion of the chapter reviewed the expression of various types of trauma, such as that experienced in air and auto crashes, and in a variety of intentional blunt force trauma.

The final section has explained the construction of bone tissue at a gross, microscopic, and ultrastructural level. The dynamics of the bone tissue components is explored; and an explanation of what constitutes a fracture provided. There is discussion of fracture types, bone response to blunt trauma, and finally the ultrastructural change experienced by bone exposed to high temperatures. With this overview, it is possible to embark upon an interpretation of the experimental material studied in this paper.

CHAPTER THREE

METHODOLOGY

When developing an experiment to test the proposed hypothesis, it was necessary to select the appropriate material and method of preparation to provide experimental evidence which may be tested (relative to the hypothesis). The procedure must be replicable, and have a minimum of variables. Care must be taken in the recording of information, via photographs, x-rays, and notes. The equipment used must be reliable. In the following chapter, the methodological procedure used in the experiments and justification for the approach will be presented.

3.1 Material

As the hypothesis suggests that traumatic fractures can be distinguished from heat-induced fractures in bone, the choice of material used was limited to bone tissue. Human material was not chosen, because the difficulty of obtaining, storing, and moving it would have been considerable for this initial investigation. Instead, the decision was made to locate suitable and feasible animal material.

The density of fresh human bone tissue, depending upon its type - cancellous or compact- has been recorded at 1.08 g/cm^3 and 1.85 g/cm^3, respectively (Blanton and Biggs, 1968). Many smaller species fall around this range; for instance, dog tibiae have been estimated in a range from 1.3-2.4 g/cm^3; kitten femora at 1.8-2.2 g/cm^3, and sheep femora at 1.42-1.47 g/cm^3.

The sheep femora were chosen, based on three factors: 1) availability, 2) size and 3) density. Eight sheep hindlimbs were available from the Department of Animal Sciences at the University of Alberta (for a minimal fee). These limbs were removed from animals which had been put down after their use in the Animal Physiology course. The limbs were intact and shorn at the time of recovery. The femur was specifically chosen as the bone of study, because of its size and locality in the body. The sheep femur and its associated soft tissue is not too large to be easily transported and stored, and it can be readily dissected from the animal. The femur is also a commonly fractured limb in air and auto accidents; and it frequently survives the process of accidental or intentional cremation, because of its density and position in a thick bed of muscle tissue. Finally, it has been shown that the density of the sheep femur is comparable to human bone. All these factors made the sheep femur the ideal bone for this study.

The segment used in the experiments consisted of the complete femur with innominate and proximal 3/4 to whole tibia. In other words, the hindlimbs were removed and hemisectioned, and the hooves were removed. This procedure produced a suitably sized sample, which fit into the experimental oven. As mentioned above, the leg was intact and skin unbroken except at the sectioned ends. Therefore, the femur was surrounded by muscle tissue and its fluids. This feature was felt to be important, in order to simulate the expected body conditions in accidents or homicides. The amount of the muscle surrounding the limb varied, but all specimens fit in a 53 cm x 30 cm tray. The size was dependent upon the age and sex of the sheep.

With regards to the age and sex of the animals, availability determined the ratios; there was no choice. The ages ranged from 7-21 months and constitute physiologically juvenile animals, although the older animals were considered reproductively mature. None of the specimens exhibited completely fused epiphyses. Table 5 presents the vital statistics on the eight animals used in the experiments. The age and sex of the animal may influence the fracturing, but this influence was felt to be minimized as all animals were relatively young and would not have undergone any major osteoporotic change. This conclusion was supported by the lack of rarefication in the pre-trauma x-ray. The largest animal was not the male as expected, but a 13 month old female (#4).

3.2 Recording Method

The second problem was deciding how to record the cremation changes in the bones. This problem was solved with two methods. Photography is a valuable tool for preservation of information, and was deemed indispensable for this study. Black and white negatives (for prints) and colour slides were taken with a Pentax 35 mm Spotamatic and a 35 mm Canon Al SLRs. The lenses used in the study included a 50 mm and a 100 mm macro.

Because it was necessary to record what was occurring to the bone beneath the skin and muscle tissues, radiographs were taken at each stage of the experiment. The x-ray equipment, a mobile x-ray machine with x-ray film/screen combination, was provided by the Alberta Office of the Chief Medical Examiner (Northern Region). All the x-rays were produced by Cyril Chan, Radiology Technologist and Photographer at the Office of the Chief Medical Examiner. The use of the x-ray for analysis was chosen for a second reason. The radiograph is a tool used routinely by forensic pathologists in the process of identification; and this practice means that it

Table 5: Vital Statistics for the Sheep Experiments.

Specimen #	Sex	Birthdate	Fracture Type	Temperature
285L	Female	April, 1988	Spiral-oblique	450°C
150L	Female	March, 1988	Transverse	600°C
147L	Female	March, 1988	Transverse	650°C
153L	Female	March, 1988	Transverse	700°C
538L	Female	April, 1988	Transverse	750°C
4L	Female	October, 1987	Spiral	800°C
213L	Female	Feb., 1987	Spiral	850°C
78L	Male	Jan., 1987	Transverse	900°C
150R	Female	March, 1988	Spiral	600°C
147R	Female	March, 1988	Comminuted Spiral	650°C
153R	Female	March, 1988	Transverse	700°C
538R	Female	April, 1988	Spiral in spongy	750°C
4R	Female	October, 1987	Spiral	800°C
213R	Female	Feb., 1987	Spiral	850°C
78R	Male	Jan., 1987	Transverse	900°C
285R	Female	April, 1988	Blind	850°C

has the benefit of being available and familiar to those individuals currently presented with cremated remains. The gross visual differentiation of the fracture type may be supplemented and/or verified by radiographic analysis. Initially the possibility of video-recording the actual cremation was considered, but the design of the oven made this consideration impossible.

3.3 Cremation Furnace

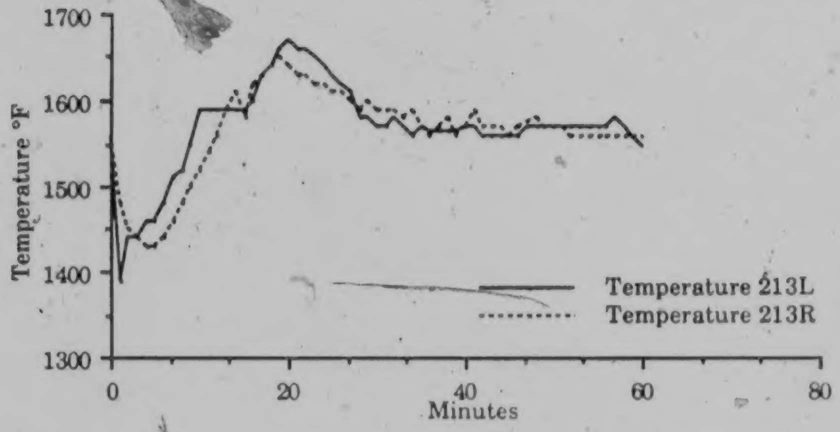
The furnace used in this research was a ventilated fire-asane furnace (see Plate 1a). This is an electric furnace with two ventilation holes in the rear. The elements run in rows along the sides. There is brick encasing the furnace; and the solid door slides down to achieve access. The stainless steel tray and sheep leg fit comfortably in the furnace, with ample room for circulation of air above the tray. The furnace was capable of achieving temperatures up to 1093°C (2000°F); however, the accuracy available was in the order of ±20° Fahrenheit. The use of the furnace was donated by the Department of Mining, Metallurgical and Petroleum Engineering at the University of Alberta.

The temperatures used in this study can be seen in Table 5; they range from 450°C-900°C (842°F-1652°F). In all but Experiments One and Two (#285L and 150L), the furnace was allowed to reach the cremation temperature before the leg was inserted, as the oven took from 2-3 hours to reach burning temperature, and this long period meant that the duration of burning of each leg would not be standard. Therefore, the oven was brought to the required temperature; the leg was then inserted and allowed to burn for one hour. At that time, the furnace was turned off and the door opened to allow for burnout and cool down. This latter period ranged from thirty to sixty minutes.

The temperature fluctuations were recorded every minute during the burning period. The accuracy of the readings were dependent upon reading a needle temperature gauge. The gauge was divided by 20° F increments; therefore an accuracy of ±20° Fahrenheit was all that could be expected. The temperature within the oven was recorded by a thermocouple which projected from the rear of the oven into the centre of the oven. Thus recorded temperatures reflect ambient temperatures and not surface temperatures. The furnace automatically shut off when the temperature exceeded the set oven temperature and turned on when temperature dropped below the desired temperature.

The graphs presented in Figure 4 demonstrate the general progression of the combustion. The temperatures climbed initially until the sample ignited and flashover occurred. Flashover generally occurred within fifteen minutes (range of 4-15 minutes), after which time the temperature would drop to the desired or set temperature. The initial flashover lasted an average of twelve minutes (range of 7-23 minutes). The temperature rose upon ignition of the fats; this process caused fluctuations in the temperature within the oven. Secondary and tertiary flashovers were common. In fact, a minimum of two flashovers occurred in 13 out of 16 experiments.

The use of a thermocouple to record bone surface temperature was rejected, for two reasons. The first reason was that the attachment of the thermocouple to the bone surface would have required an invasive procedure, which would have allowed heat to access the bone more rapidly, and introduce one more variable for interpretation. Secondly, the



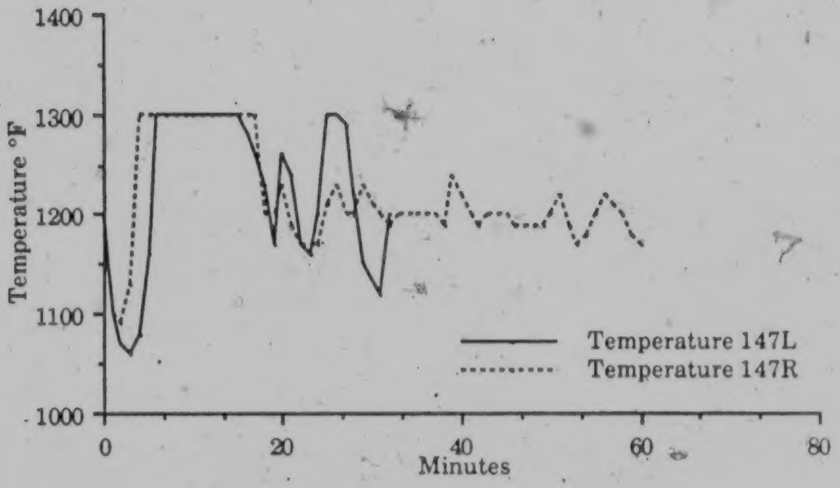


Figure 4: Temperature fluctuations I: a) This graph demonstrates the similarity in the temperature fluctuations from the right and left leg of the same specimen cremated at 850°C and b) this graph demonstrates the fluctuations in temperature of the right and left legs of a specimen cremated at 650°C.

thermocouple would record only the temperature reached at that specific location. If, for example, the thermocouple was attached on the tibia (thin muscle layer), this area would have a potentially higher temperature than the proximal end of the femur (embedded in thick muscle tissue). Only when the bone is defleshed or dry is it logical to use a method of recording surface temperature.

3.4 Fractures Observed in the Experiments

When testing for the presence of traumatic fractures in cremated bone, there must first be a traumatic fracture. Two types of fractures were produced. The equipment designed to traumatize the sheep femora were experimental in nature. Two set-ups were designed and tested (see Plate 1b and 2a). The first was intended to produce a transverse fracture in the femur. The femur was supported at each end; then a weight was dropped upon a bar. This bar forced the bone to bend and fracture transversely due to angulation (compression with no axial loading). This set-up was successful once the weight from the maul (a large hammer) was directed to the bone through the metal bar. This procedure produced a 454.82 kg/cm stress upon the bone. The weight was insufficient to produce a complete fracture with one blow; a mean of two blows was necessary.

The second set-up was developed to produce a spiral fracture. This piece of equipment was designed like a guillotine. The pelvic end of the leg was clamped firmly in a vice; the distal end of the tibia was attached via a wire to a floor board. The torsion on the bone was created by positioning a wedge underneath the femoral-tibial joint. This force lifted and twisted the femur. The guillotine blade was angled so as to propagate the spiral fracture in the long axis of the bone. A weight of 7.31 kg was dropped a distance of 139.7 cm. This procedure produced a stress of 1021.2 kg/cm upon the bone. At this weight and distance only one blow was required to fracture the femora. This second device was far superior to the initial one, and could easily have been adapted to produce the transverse fracture. Unfortunately, its development occurred after the first eight legs were cremated.

The first eight legs (left legs) were fractured transversely. In all but two instances this process was successful. Force applied to legs #4L and #213L resulted in oblique comminuted and spiral fractures, respectively. A spiral fracture was attempted in the second group, (ie., the seven right legs). One leg, #285R, was retained for a blind test to be run at the end. Of these seven, two were unsuccessful, in that #147R and #153R had comminuted fractures. #147R was crushed, and #153R had a transverse fracture (see Table 5 for summary).

3.5 Procedure

Now that the method of procurement, storage, traumatization, and cremation is understood, the exact procedure will be described.

Step 1: X-ray of the frozen, untraumatized limb in antero-posterior (A-P) and medial-lateral (M-L) views at the Office of the Chief Medical Examiner (OCME). The x-ray was then searched for evidence of previous (antemortem) trauma. "Pre-trauma x-ray"

Step 2: The limb was allowed to thaw overnight.

Step 3: Traumatization of the thawed limb to produce a transverse or spiral fracture.

Step 4: X-ray of the traumatized limb (A-P and M-L) at the OCME. "Post-trauma x-ray"

Step 5: Photograph of the leg in the stainless steel pan before insertion into the oven (Black/white and colour).

Step 6: The leg, within the pan, is placed in the hot oven (except in the first two instances) located at the Mineral, Mining and Petroleum Engineering Building. The leg is allowed to burn for one hour at the desired temperature. Temperature readings are made every minute. After one hour, the oven is turned off and opened; this procedure allows the leg to cool. Time for this process ranges from 30-60 minutes. The leg and pan are then removed from the oven.

Step 7: Photographs of the remains in situ in the pan (B/W and colour) are taken.

Step 8: Transfer of the cooled remains from the steel pan to plastic container for later x-ray is completed, and the positioning of the fragments is maintained.

Step 9: Removal of the cremated remains to the OCME for an x-ray in the A-P and M-L views. "Post-cremation x-ray"

Step 10: Removal of any remaining soft tissue (at U of A Faunal Lab).

Step 11: Storage of the remains in open racks to allow for air circulation. The racks are padded with foam padding to reduce damage.

Step 12: Analysis: photography and further x-rays when needed.

This procedure was meticulously followed for each leg. With this method the author was provided with fifteen legs, which had recorded evidence of traumatic fractures of two main types, and of heat-induced fractures at a variety of temperatures. No control femora (ie. not burned, or not traumatized) were necessary, as the tibia on each leg was not traumatized and therefore experienced only heat-induced fractures (self-made control).

3.6 Blind Test

The final leg (#285R) was used in a blind run, in which the leg was "traumatized or not" by colleagues. The colleagues, then x-rayed and burned the leg without the participation of this researcher. The blind run was used to test the conclusions drawn upon the known sample. The blind run was completed at a temperature of 800° C (1472°F), in order to ensure the removal of all soft tissue. As this last process was completed by others (J. Mayne and C. Duarte) not intimately involved in the project, it was felt necessary to avoid the presence of tissue. The researcher was presented with the disturbed cremated remains and x-rays of the remains after disturbance. In situ photographs and x-rays were kept separate. Precremation x-rays were kept separate and unavailable to this researcher until the analysis was completed.

With the experimental procedure presented here, it was possible to examine the hypothesis which questions the ability to distinguish precremation traumatic fractures from heat-induced fractures in bone tissue.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Recovery

Analysis of the fifteen experiments will provide the evidence required to substantiate or negate the hypothesis presented. The acceptance of the hypothesis will be beneficial to those professionals analyzing trauma in individuals who have been cremated; however, negation of the hypothesis will also be beneficial, as the time spent attempting to find evidence of trauma may be applied more efficiently to other aspects of interpretation of the cremated bone.

In the following pages, the results of the sixteen experiments will be presented; and an interpretation of the results will be made. The analysis has suggested that there are several factors involved in the identification of precremation trauma in cremated bone. Recovery, reconstruction, and comparison are all aspects of a successful identification; and will be thoroughly discussed.

4.1.1 Collection practices and in situ observation

The first factor involved in the identification of precremation trauma is the recovery. Often situations arise in which recovery of human remains can not be as complete or rigorous as desired (for example, an apartment fire), and this failure must be accepted as a factor in the later analysis. In the experiments completed here, recovery was simple and complete. All surviving bone fragments were retrieved for analysis. This is the ideal situation; however, real life often presents us with harsher realities. In air crashes, material may be spread over vast areas; collapsing buildings may bury or scatter remains; and disturbance by observer/participants may alter positioning and destroy contextual evidence. These are conditions which will influence the effectiveness of the analysis, and are beyond the researcher's control. However, whenever possible, recovery of the cremated material should involve the use of in situ photographic records; and the researcher should make close observations and sketches of the relationship of the bone fragments. Where practical, excavation and recovery of the remains should include the participation of the individual(s) completing the analysis. This observation is important for later visualization of the relationships of the bone fragments.

Once the remains have been recorded in situ, careful recovery should begin. This procedure is best accomplished after the remains have been allowed to cool. The hot cremated bone is extremely fragile, and may crumble before it can be lifted and packaged. It is important to attempt to retrieve as many of the bone fragments as possible, as even the minutest fragments may be valuable in the reconstruction of the bones. Transportation of the remains can be the key to a successful analysis. Additional shattering and abrading of this material can easily occur in unknowing hands. It must be remembered that the analysis of the remains can only be as good as the quality and quantity of the recovered material.

The material should be radiographed prior to any removal of soft tissue. In this way, evidence from the contraction of the remaining muscle tissue encasing the bone may reveal the presence of trauma immediately. In post-cremation x-rays of specimens #285L, #153L, and #538L, there was evidence of the traumatic fracture provided by the muscle contraction and related bone movement. The inferior portion of the femur was pulled superiorly as the hamstring and quadricep muscles contracted during desiccation in the dehydration stage of cremation. The relationship of the bones was maintained, because the muscle mass remained associated with these specimens. The transverse traumatic fractures were clearly identifiable (Plates 2b and 14a).

When muscle tissue is not present to maintain the association, it may be possible to view the fracture in situ prior to recovery, if no disturbance has occurred. This evidence can be obtained only in instances when the in situ evidence is recorded. It was found that the traumatic fracture could be easily located in most instances by this researcher when viewed in situ, either in gross observation or on the x-ray (Plate 3a). Only when higher temperatures were reached, and fragmentation was severe, was this matter complicated. The transverse fractures were more obvious than the spiral, but this issue will be addressed later in more detail.

4.2 Reconstruction

In these experiments, the remains were x-rayed and photographed in situ, and then the remaining tissue was removed manually prior to storage. Storage took its toll on the remains, as many bones which initially remained together, fell apart along the heat-induced fracture lines. No conservation procedure, such as dipping in a water and white glue solution, had been completed on the remains prior to storage. This procedure would have effectively altered the bone surfaces, an effect which was undesirable. Because of this deterioration, it was felt that some reconstruction was required to view the traumatic fracture margins. Reconstruction was undertaken without the use of photographs or x-rays in order to establish the possibility of identifying the traumatic fracture in the process of reconstruction.

The results of the reconstructions were surprising. In all of the transverse traumatic fractures, the reconstruction was completed and the articulation of proximal and distal halves was readily identifiable (Plate 3b). The spiral and comminuted traumatic fractures were not as cooperative; in fact, three instances arose in which portions of the traumatic fracture margin were not accurately reconstructed (specimen #213L-spiral, #147R-comminuted transverse, #4R-spiral). In these cases, it was only after comparison with the post-trauma x-rays that the error became obvious. This effect is a complicating factor in the analysis. The problem of comminuted fractures and spiral fractures was not solved at this level of the analysis. However, this problem will be addressed later in this discussion.

One technical consideration in reconstructing cremated bone was the use of a water-soluble white glue. If the fragment has been misaligned, white glue can be loosened and remnants can be cleaned from the surfaces. Burned bone is extremely porous and brittle; therefore care must be taken in the handling of the tissue. The decision to glue fragments must take into consideration the alteration of the bone tissue which this process produces. The value of this process may be outweighed by the value of the tissue for further research analysis. Histological analysis will be adversely affected, and the pressure required to seal the glue may cause the bone to crumble.

The analysis may potentially be concluded at this stage if the traumatic fracture has been identified (Plate 3b). The importance of understanding the characteristics of traumatic fractures, as described previously, and a knowledge of the biomechanics of traumatic fracture propagation is obvious (refer to Chapter 2). Therefore, with in situ observation, careful recovery and reconstruction, precremation trauma may be located and recorded early in the analysis.

4.3 Identification of Heat-Induced Fractures

If in situ evidence and reconstruction were inadequate for a confident identification of the traumatic fracture, it is necessary to begin a close examination of the various fracture types observed in the reconstructed segments with comparison to the post-cremation x-rays.

The characteristics of heat-induced fractures and traumatic fractures are the result of the type of stress experienced, and the nature of the tissue matrix involved. It is logical that the fracture produced in a brittle material by a static load would be different from that produced by a dynamic load in ductile material; therefore based on this assumption, it follows that heat-induced fractures should be different from traumatic fractures. At a gross level, this, in fact, appears to be the case. The evidence for this distinction is provided by comparison of the "known" traumatic fracture margins with those of the heat-induced fractures in fifteen experiments completed in this study.

The concept of the brittle nature of bone has been presented in Chapter Two and will not be repeated here, but it is important to understand how the "DDIF process" produces this brittle material. As the bone tissue undergoes cremation, it gradually loses its water and organic components (dehydration and decomposition). This process removes the structural half of the bone matrix which is responsive to tensile force. The bone matrix is, then, more susceptible to compressive and tensile forces. As the static weight of the bone tissue and the internal static pressure of the bone marrow act upon the brittle bone tissue, the results are heat-induced fractures of five general types.

The first type of heat-induced (HI) fracture is the longitudinal fracture (see Figure 5a and Plate 4a). The longitudinal HI fracture is characterized by the orientation of the fracture through the shaft in a direction parallel to the long axis of the bone (Plate 4a). The observation of this type of fracture is not new, as Binford (1963) and Baby (1952) discussed its presence in dry and defleshed cremated bone. This fracture can be found at very early stages in the cremation. In specimen #285L, burned at 400°C for a minimum of half an hour, there were already longitudinal HI fractures. The presence of these fractures increased as the temperature was raised. For example, while #285L had two main longitudinal HI fractures, #153R, burned at 700°C for one hour, had a minimum of seven identifiable longitudinal HI fractures.

The longitudinal HI fracture appears to be initiated at a distance from any previously produced traumatic margin; and extends to that margin, whereupon the longitudinal HI fracture is arrested by the transverse traumatic fracture, the spiral traumatic fracture, or by a previously formed HI fracture. When viewed on the x-ray, the longitudinal HI fracture had a sharply defined border (Plate 4b). Often there was some warping associated with this fracture. Specimens #78L, #153R, #538R, and #150L had evidence of this latter condition (Plates 5a and 5b). On the x-ray of #538R, this fracture was located in the cancellous tissue at the epiphyses; and it extended down the shaft. The fracture appeared faint and indistinct in the cancellous bone, but then broadened; and was defined in the cortical bone of the shaft.

This first type of HI fracture is the most problematic; as it may take a somewhat helical path along the bone, and therefore mimic the spiral traumatic fracture (Plates 5b and 12a). This problem is not easily resolved at the gross or radiological level. It will require analysis at the ultramicroscopic level to differentiate the two. One aspect of the spiral traumatic fracture is its continuity around the entire circumference of the bone, while the longitudinal HI fracture is not circumferential.

The curved transverse fracture is the second type of HI fracture (see Figure 5b, Plates 6a and 6b). It is also commonly referred to as the 'thumbnail' fracture. In previous studies, this feature was associated only on bone burned with the flesh (refer to chapter 2). The curved transverse fracture was observed on specimens #213L, #538L and #78L, and on all tibiae (Plate 5a). It is associated with a greater exposure to the flame and heat.

The external surface of the bone at the location of the curved transverse fracture is characterized by a series of stacked curved fractures. If the bone is separated at the fracture, the cortex is convex on the superior margin, and concave inferiorly (Plates 6a and 7a). This feature produces the characteristic rounded appearance. The periosteum has, apparently, been separated from the compact tissue.

The curved transverse HI fracture can be identified on the x-ray (Plate 6b). These fractures may extend through the cortical bone, and travel around a portion of the circumference; and can, therefore, be viewed with clarity on the post-cremation x-ray.

The straight transverse or step fracture (refer to Figure 5c) is the third type of heat fracture. The step fracture is usually associated with longitudinal HI fracturing (Plates 4a and 4b). Step fractures are short

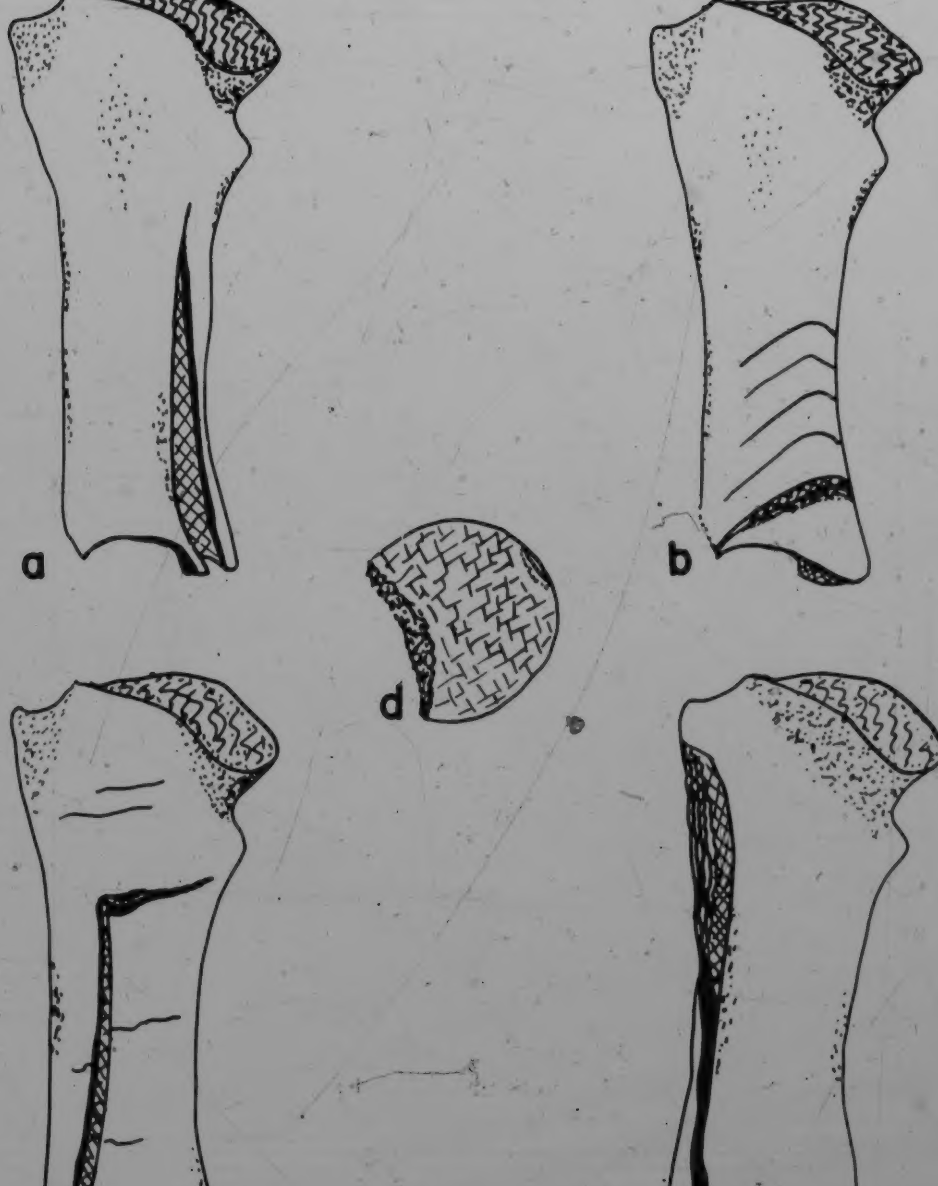


Figure 5: Heat-induced fractures: a) longitudinal, b) curved transverse, c) straight transverse, d) patina, e) delamination.

fractures which intersect the longitudinal fractures, and are then arrested. In the experiments in which bones were exposed to higher temperatures, step fractures appeared more frequently. Specimens #213L (850°C), #78L (900°C), and #285L (400°C) all had identifiable step fractures on the femur. The tibiae, which were more calcined throughout, exhibited step fractures frequently (Plate 7a).

When viewed on the x-ray, the step fracture is characterized by its length; it rarely travels far around the circumference of the bone. When the bone fragment is separated from the main body of the bone, there is an initial similarity to the transverse traumatic fracture, except that only a portion of the bone surface is involved. The step fracture was never seen to include the entire circumference of the bone (Plate 7b).

An interesting type of heat-induced fracture is the "patina" fracture (Figure 5d and Plate 8a). This fracture was the earliest described by Krogman (1945), who coined the phrase "like the patina of an old painting". Another way of describing the characteristics of this type of fracture pattern is that of crazed china. The fractures do not extend through the entire thickness of the cortex, but rather affect the outer layers. Most commonly, these fractures are located on the epiphyses and in regions with underlying cancellous bone. The femoral heads of specimens #538L, #153R, #4R, #4L, and #213L demonstrated the patina fracture. The patina fracture was rarely demonstrated by the x-ray. In this respect, it was not confused with the traumatic fracture types studied here. The patina may be found in highly calcined bone upon the shaft, but this occurence is not common.

The final type of HI fracture which is observed in cremated bone tissue is the delamination fracture (Figure 5e and Plate 8b). This fracture

Type	Characteristics
Longitudinal	•parallel to long axis of the bone •may curve slightly around axis •sharply defined appearance on the x-ray
Curved Transverse	•thumbnail fracture •stacked curved fractures •associated with higher temperature exposures
Straight Transverse	•horizontal fracture •may intersect longitudinal fractures or be located at their extremity •travels a short distance around circumference of the bone
Patina	•'patina of an old painting' or crazed china •rarely deep enough to be demonstrated radiographically
Delamination	•Splintering away of endosteal and periosteal lamellae •separation of cortical bone from cancellous bone •exposure of cancellous bone on epiphyses

Table 6: Characteristics of Heat-Induced Fractures

is characterized by the splintering away of series of layers of bone (Plate 9a). It would appear that successive layers of lamellae are separated from the main cortical bone. The result is the exposure of the inner cortical bone. As temperatures increase, warping and delamination are associated (Plate 5a); some examples of this feature were found in specimens #78L, #78R, #4L, and #538R.

When viewed on the x-ray, delamination may be seen as buckling (puckering), or thinning of the cortex (Plate 9b). Delamination frequently occurs over areas of cancellous bone. The outer thin layer of cortical bone appears to separate and peel away from the trabeculae. In this type of HI fracture, the epiphyses are often affected. The cancellous tissue of the epicondyles of the femur are often exposed, as was seen in #147L, #153L, #153R and #4R.

It is important to stress that when a fracture is not characterized as one of the five main types of HI fractures, it is not possible to conclude that the fracture is of traumatic etiology. Other factors must be considered. The process of identifying the traumatic fracture by the process of elimination must include a consideration of the 'natural' characteristics of traumatic (violent) fractures in unburned bone tissue. These characteristics have been dealt with in some detail in Chapter Two, and it is not necessary to reiterate all of these points here.

4.4 Identification of Traumatic Fractures

Once all HI fractures are identified, the researcher can then begin to analyze the remaining fracture margins. If reconstruction has been relatively complete, the characteristics of transverse fractures may be evident. The gross appearance of the closed transverse traumatic fracture is a fracture which is continuous around the circumference of the long bone at a constant level (Plates 3b and 10a).

In the current experiments the reconstructions were complete enough to reconstruct the entire superior and inferior margins of the traumatic zone. The temperature affected the ability to articulate the margins of some specimens completely -high temperatures produced more distortion of the bone; however, the majority of specimens were not calcined at the traumatic fracture margin, because of the presence of thick leg muscles. The margins of the latter specimens could be articulated closely. Specimens #235L, #147L, and #147R (max. 650°C) were not carbonized in this region (Plate 10a). #150L, #153L, #538L, and #153R had some carbonization; but calcination was restricted to the ends of the shafts. The maximum temperature for these specimens was 750°C. Of the transverse traumatic fractures, #78L/R (at 900°C), were severely calcined on the margins. These latter cases still exhibited a region on the midshaft, in which the traumatic fracture encompassed the entire circumference; but because of warping and delamination the fragments could be articulated only around a portion of the circumference (Plate 10b).

It would seem that in temperatures less than 650°C, trauma should be easily identified; but only in situations when the muscle mass has survived to protect the bone tissue. From 650-850°C, the muscle mass was removed completely, thus exposing the bone tissue to the effects of the DDIF process more directly. However, this development did not prevent the identification of the transverse traumatic fractures. Above 850°C, the exposure was extreme; and warping was the greatest problem.

The greatest handicap to the identification of this type of fracture is the recovery of the bone fragments. If enough reconstruction can be completed, identification is straightforward at the gross level of observation. Viewing the reconstructed remains by x-ray aids little in their interpretation. The transverse traumatic fracture in #150L can be clearly viewed in the x-ray (Plate 11a). It may be fruitful to realign the upper and lower segments, to examine the heat-induced fractures to establish that they are arrested by the previously produced traumatic fracture. This latter step can be completed also by gross observation.

The ease with which the transverse traumatic fracture is identified may be dependent upon the dynamics of bone tissue. The HI fractures, as presented earlier, are thought to respond to a static load, and fail along natural structurally weak areas. The transverse traumatic fracture is, conversely, the product of a dynamic load "against the grain" of the bone tissue. The fracture is forced in a certain path because of the magnitude of the stress. As will be demonstrated shortly, these elements are in contrast to the spiral traumatic fracture, which propagated along natural lines of weakness.

The second type of traumatic fracture analyzed in these experiments was the closed spiral fracture of the femoral shaft. In specimen #4L and #213L, there were comminuted spiral fractures. The remaining specimens #150R, #538R, #213R, had simple spiral fractures. The extension of the helix along the shaft varied for each of them.

The amount of calcination present on these specimens was substantially higher, and was reflected in the temperature exposure. Leg #150R (600°C) was the only one in which the traumatic fracture margin was unburned, and #78R (900°C) was completely calcined. The remaining specimens (#213L, #538R, #4R #213R, and #4L) ranged in temperature from 750°C-850°C, and exhibited varying degrees of carbonization and calcination. In the noncarbonized specimen (#150R), burned at 600°C for 1 hour, the spiral fracture was easily recognized. The fracture was partly transverse, and then spiraled down the shaft. There were no HI fractures associated with the diaphysis (Plate 14a).

The second group of spiral fractures, those with carbonization and/or calcination at the fracture margin, included specimens #538R, 4R, 4L, and 213R/L. Speciman #538R was interesting because the fracture had extended into the spongy distal epiphysis. Once the fracture invades the trabecular tissue, it has a tendency to radiate and anastomose (Plates 11b and 12a). In #538R, the spiral was shortened; and was not a true 45° helix.

The articulation of the upper and lower segments was possible, but there was some warpage of the proximal shaft fragment on the posterior surfaces. This feature was associated with two longitudinal HI fractures. This bone required a great deal of reconstruction to rebuild the lower margin of the proximal shaft, so that articulation might be attempted. While the spiral traumatic fracture was characterized by a continuous helical fracture around the circumference of the bone, the longitudinal HI fracture did not extend beyond the lower margin of the proximal shaft into the distal shaft fragment (Plate 12a).

An interesting situation was presented by specimen #4R (800°C); it had a spiral fracture which was comminuted. Five fragments of bone were produced at the point where the dynamic load contacted the bone. The fragments ranged in size from 9.30 x 8.48 mm to 63.56 x 26.28 mm. It was possible to identify the spiral fracture by the realignment of the fracture margins and the observation of the continuation of the fracture on the proximal half of the bone into the distal half. This was not a satisfactory situation. The upper reaches of the spiral mimicked the curved transverse fracture, and may be confused with it. Examination of the x-ray did not clarify this situation to any great extent. The tissue which was associated with the bones was insufficient to yield any clues. The fracture appeared transverse and not spiral.

Comminuted fractures present a substantial barrier to the identification of a traumatic fractures, because of their nature and the fragmented condition of the cremated bone. This situation may be different in analysis at the histological level; but it is felt gross, and x-ray observation is not adequate to distinguish between the heat-induced fractures and severely comminuted traumatic fractures. Histological observation will provide a more precise view of the pattern of fracture through the bone structures.

The identification of the traumatic spiral fracture on specimen #4L (800°C), was simpler, because there was no comminution; the spiral was more oblique and the fracture margin was not calcined, but the margin was partially carbonized. The distal portion clearly demonstrated the spiral traumatic fracture, and was easily realigned with the proximal segment. Although the proximal femur had several HI fractures, these did not distort the characteristics of the helical spiral. The location of the spiral fracture was apparent on the post-cremation x-ray film. The bone was located within a contracted muscle mass, and the overlap of the superior and inferior portions of the femur was located. This specimen (#4L) had a bone pathology on the distal extent of the shaft, just above the lateral condyle. This was a circular area of denser bone. The bone protruded into the marrow cavity, and was not observable on the external surface. The discovery of this defect (osteoma) was first made on the x-ray film. The one large heat fracture on this distal portion circumvented this denser bony area.

The final specimens in this group of incompletely calcined femora with spiral fractures were #213L and #213R (cremated at 850°C for one hour.) #213L had a comminuted spiral fracture with a minimum of four associated fractures (Plates 4a and 4b). There was a large fragment (42.15 mm x 23.03 mm) from the anterior surface of the distal femoral segment. This fragment was initially glued in place on the supero-anterior surface of the distal fragment, as it appeared that this was a longitudinal HI fracture with accompanying step HI fracture. The mistake was only rectified with reference to the 'post-trauma x-ray'. This bone was grey-white to white in colour, with numerous HI fractures upon the shaft. Even with this mistake in the reconstruction, it was possible to recognize a continuous traumatic fracture margin intersected by HI fractures on the proximal segment of the femur. It was possible that the confusion with the distal fragment was produced, because the step-like fracture was located in the cancellous tissue at the epiphysis. In the post-cremation x-ray, the upper margin of the traumatic fracture may be readily identified; but the lower was obscured by displaced bone fragments (Plate 4b). Here, then, is another example of how the accompaniment of comminution with the spiral traumatic fracture makes for a difficult and uncertain analysis.

The right femur of specimen #213 provided a clearer picture of a spiral. This bone, burned also at 850°C for one hour, was grey-white to white; and had numerous HI fractures (Plate 12b). The spiral traumatic fracture was not easily identified before reconstruction, because of several longitudinal HI fractures parallel to the spiral traumatic fracture. Once reconstruction was completed, however, the spiral fracture was obvious. Articulation of upper and lower halves was relatively good, in relation to the degree of calcination and warpage (Plate 13a). The post-cremation x-ray did not significantly increase the ability to locate the spiral traumatic fracture, as all of the tissue was gone; and the fragments from the shaft had collapsed around the bone. However, there was a suggestion of a traumatic fracture in the separation of the upper and lower segments (Plate 13b).

The spiral traumatic fracture presented the researcher with considerable difficulties, as shown here, when the material was in the more advanced stages of calcination and fragmentation. If reconstruction is not possible, there is little to no chance of traumatic fracture identification. Even with adequate reconstruction mis-identifications are possible, due to the longitudinal HI fracture mimic effect of the spiral traumatic fracture. There is an explanation for this situation, if one remembers the manner in which the spiral traumatic fracture is propagated. The femur, which is axial loaded, has a twist or rotation in the shaft when the dynamic load contacts it. The failure of the bone is in the line of least resistance. In the case of the spiral traumatic fracture, relief from the rotation pressure is achieved by failure in this stressed area. The fact that the earliest type of HI fracture located in bone tissue is the longitudinal fracture suggests a relationship between these two types of fractures. Once the bone loses its water content, it is plagued by longitudinal HI fractures. This splitting may relate to the structural arrangement of the collagen and HAP crystals. The loss of the water may produce a weak interface between the components, and hence an area of weakness. If the organization of compact bone is recalled (see Chapter Two), the lamellar organization and orientation of collagen fibres and their associated HAP crystals provides the bone with a natural structural weakness. If the anisotropic nature of the organic and inorganic components is reduced, or if the stress upon the bone exceeds its strength, the bone will fracture parallel to the long axis of the bone, or as near as possible. This explanation for the confusion between spiral traumatic fractures and HI fractures requires testing through ultramicroscopic studies; but at this stage, it is a viable interpretation of why spiral traumatic fractures are more difficult to identify than transverse traumatic fractures in cremated bone.

4.5 Further Characteristics

There were three further characteristics associated with the appearance and identification of the traumatic fracture in cremated bone. The first two were observed more frequently in association with traumatic fractures, but can not be used alone to verify the classification as a traumatic fracture.

4.5.1 Appearance on the x-ray

The appearance of the traumatic fracture margin on x-ray film was indistinct, or blurred. This characteristic was a reflection of the nature of radiograph production. The margins of the traumatic fracture were not smooth, but had discontinuities. The cortex was thinner in some areas than in others, and therefore the density through which the x-rays penetrated was variable. In contrast, the HI fractures were smooth-edged; and the rays penetrated these margins equally. The result was an indistinct border on the traumatic fracture margin and a distinct one on the latter (Plates 5b and 11a).

A second reason for these differences may relate to the scatter of the x-rays as they move away from their source. As a result of this, the farther an object is from the radiographic film, the greater the scatter. The implication of this feature is that it may merely be coincidental that a distinction in the borders of the fractures can be noted. The value of the observation of the sharpness of the fracture margins on radiographs may be of limited value.

4.5.2 Adhesion of soft tissue

Another observation which may be made at the traumatic fracture margin is the presence of congealed fluids or tissue. The glassy appearance of blood and interstitial fluids in the region of the trauma, and not in the areas of HI fractures, may be explained by the sequence of events (stages) in the cremation process. The traumatic fracture occurred first, and exposed two surfaces of cortical bone to fluids in the muscle and myleloid tissue. These fluids escape into surrounding soft tissue, and coat the hard tissue surfaces. Once the temperatures begin to rise, the dehydration leaves behind an anhydrous material which is fused (dryed) onto the outer bone surface. The heat fractures begin to occur after the water content is largely removed; therefore it is reasonable to assume that these surfaces are less likely to have fluids crystalized (fused) or congealed upon them (Plate 14b). Examples of this characteristic were found on specimens #213L, #538L, #153L, #150L, and #4R.

The presence of tissue was observed on the carbonized and unburned margins of the traumatic fracture and on the outer surfaces of the bone. As the cremation proceeds, this tissue was completely consumed. The observation of tissue and fluids adhered to the fracture margins can at best be considered circumstantial evidence for the presence of a traumatic fracture. This observation, like the indistinct appearance of the traumatic fracture on the x-ray, must be supported by evidence gained from in situ data, and analysis of fracture types.

4.5.3 Impact point

A final consideration in the interpretation of trauma in cremated bone is the identification of the impact point produced by the dynamic force.

The search for evidence of flaking produced in bone breakage has been sought by archaeologists attempting to understand food utilization techniques and tool production (Bonnichsen, 1979; Johnson, 1985). It is standard procedure for these researchers to relocate the point at which the bone was hit in order to break the shaft for marrow extraction. This procedure is valuable also for the researcher analyzing cremated bone. Flake or chip removal is not produced by internal bone forces, but requires an external force to occur. Because the impact point is associated with intentional bone fracture, it was looked for in the specimens studied in this project.

The impact point is characterized by an area in which there are depressed flakes of bone removed from the edge of bone (Plate 15a); or by the depression of an area of bone, which may result in a "punched out" appearance in the bone (Plates 12a and 10a). Naturally, in the specimens cremated at lower temperatures (>650°C), the impact points were easier to locate. In the grey-white specimens, (700-850°C), it may be possible to confuse the impact point with the start of delamination. However, careful analysis should prevent this mistake.

In all but three instances, the point of impact could be identified. This feature was observed in bones with spiral and with transverse fractures (#285L, 147L, 147R, 150L, 538L, 150R, 538R, 4R, 4L, 213L, 213R, 153L all successfully demonstrated impact fractures). The exceptions were specimens 153R (700°C) and 78L/78R (900°C). Femur #153R was fragmented by the heat, and some of the fragments were lost when the tissue was removed after cremation. The inability to establish the point of impact did not hinder the identification of the traumatic fracture, as other characteristics were sufficient. Likewise, with specimen #78L/R, the impact points were uncertain. The warping, severe calcination, and poor articulation of the upper and lower segments were to blame.

The use of x-rays for this latter identification is not possible. The change in bone is very small, and is not reflected in the x-ray film. If articulation is required to locate a small area of depressed bone, the film will not be of much service.

It is important to realize that the recovery of as many fragments as possible is vital to this part of the interpretation. Reconstruction may yield the key to understanding where the bone received the blunt force trauma prior to cremation.

4.6 Blind Test

Once the analysis presented above was completed and recorded, then analysis of the blind test was undertaken. It was thought to be important to establish criteria used in the identification of traumatic fractures before testing these data. As the remains of #285R (the blind test) were delivered to this researcher in early December, 1989, they were left almost three months in a covered, unsealed container in storage before analysis. The x-rays and photographs were also stored without viewing. Finally in early April 1990, the remains were viewed for the first time, as were the post-cremation x-rays. The first view was of a container of severely calcined and fragmented remains. There was a small amount of debris remaining from cremation, but no soft tissue. Specimen #285R was cremated at 800°C for one hour, and allowed to cool before removal from the oven. The degree of calcination was in excess of that associated with #4R and #4L (also cremated at 800°C). The difference in the degree of calcination can be explained by the difference in the size of the specimens; #4 was an extremely large female. The colouration of the femur #285R varied from blue-grey to white, and the texture was extremely friable. The epiphyses were separate but complete, and the tibial fragments which survived were white calcined. There was a considerable amount of warpage of the longer bone fragments.

Some 46 bone fragments were identifiable; and associated with the innominate, patella, tibia, and femur. The femoral fragments numbered fourteen plus three epiphyseal portions (head, greater trochanter, and distal epiphysis). The largest femoral fragment measured 103.14 mm x 20.35 mm, while the smallest fragment was 9.31 mm x 5.66 mm. These measurements were taken with a Mitutoyo caliper, and represent the widest and longest parameters.

The typical heat-induced fractures described above could be identified, including the longitudinal, curved and straight transverse, patina, and some delamination.

In situ evidence was not helpful in determining the presence of traumatic fractures in this case, as much disturbance of the remains had occurred. This disassociation of the remains was intentionally done by the radiologist for a second set of post-cremation x-rays, and transportation also added to their movement. It is apparent that my colleagues intended to make the analysis as difficult as possible.

The x-rays, for my reference, were from the second set of post-cremation x-rays; and represented very disturbed remains. The medial/lateral view demonstrated the superimposition of the various bone fragments, and obscured the various fractures. It was therefore of little value in the analysis. The A-P view was clearer, as there was no overlapping of fragments. From this view, it was possible to identify four main sections of the femur, plus the epiphyses. These sections included two large proximal shaft fragments and two small distal fragments. Heat-induced fractures were identifiable and comparable to the gross morphology observed. From the x-ray, it was possible to establish the only possible location of traumatic fracture in the distal third of the femur. No conclusive evidence was drawn, however.

It was necessary to begin reconstruction of the fragments. Reconstruction consisted of the realignment of margins which were characteristic heat-induced fractures. When warpage, which was excessive, prevented realignment, the bone was not forced. The reconstruction of the fourteen fragments resulted in two segments. The first segment, the proximal two-thirds, was assembled from ten fragments. The warpage of the segment began at the midshaft, and bent anteriorly and posteriorly. The distal segment (the second portion) was mainly cancellous tissue, and had undergone a large degree of disintegration. Four fragments comprised this section (Figure 6).

It was not possible to glue this lower third to the upper, because of the warpage of the latter. However, it was possible to realign the entire circumference. The association of upper and lower portions did not produce the characteristics of transverse, spiral, or oblique traumatic fractures. There were continuations of heat-induced fractures through the sections. There was only one instance in which a longitudinal fracture was arrested by a transverse fracture. This feature was isolated, and did not continue around the entire circumference of the bone.

It was possible that this portion of the bone experienced an infarction, but the evidence obtainable from the cancellous bone was not conclusive

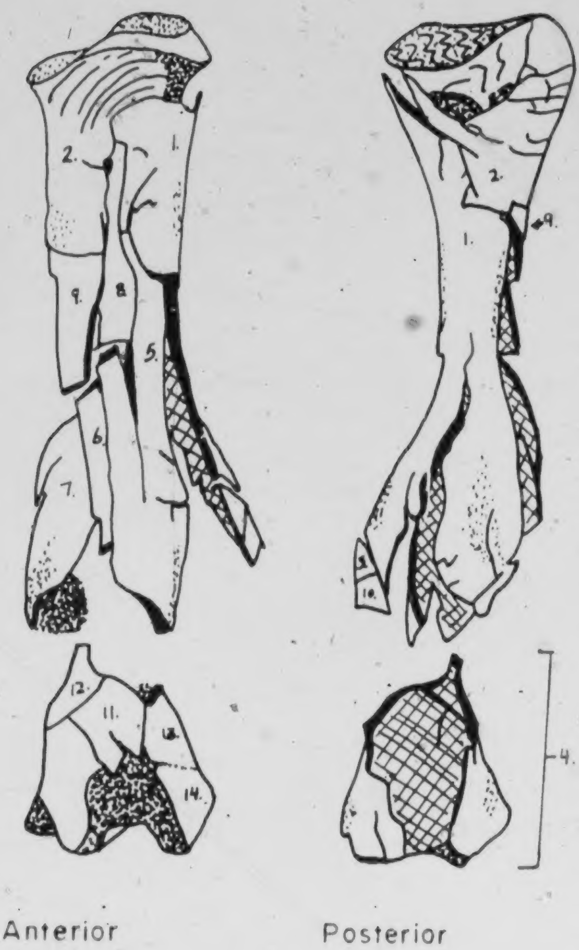

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Figure 6: Anterior and posterior views of the reconstructed blind test, #285R, demonstrate the quantity of fragments resulting in the cremation and their relationships. The two main segment can be articulated, but warpage prevents reconstruction. There is no evidence of a traumatic fracture. (Not to scale)

(this feature occurred between fragments #12 and #11). This fracture was located in the post-cremation x-ray and was heat-induced in nature.

Finally, there was no evidence of an impact point on any of the femoral fragments. There were no depressed areas, or flaked margins. The margins were too heavily calcined for the identification of tissue, or fluids on fracture surfaces; so this characteristic could not be viewed. On x-ray, the fracture margins were very distinct except for fractures penetrating into cancellous regions. In these regions the margins were not defined.

The conclusion, then, of this analysis of the blind test leg #285R (Plate 15b), was that there was no evidence of a traumatic fracture. The presence of an infarction on the distal cancellous bone could not be overruled, nor could it be substantiated. Therefore, my conclusion to the question of whether #285R was traumatized prior to cremation was: there was no evidence of a traumatic fracture.

The results of this analysis have been presented to my colleagues, who performed the experiment; and they verified the results. The "pre-trauma x-ray" and the "post-trauma x-ray" illustrate a complete femur, with no traumatic fracture or infarction. There was a small area on the shaft which appears denser (more radio-opaque), but was not a discontinuity in the bone. The epiphyses were incompletely fused, and the posterior acetabular line of fusion can be observed on the 'pre-cremation x-rays' and on the innominate fragments after heat treatment. This fragment was not included in the post-cremation x-ray, and therefore could not be compared.

It was revealed to this researcher that a second set of x-rays were taken after the cremation and before disturbance. These x-rays (A-P and

M-L) demonstrated the continuous nature of the femur, with associated heat fractures. There was no possibility that a traumatic fracture could be present. The individuals completing the experiment must have realized how simple it would be to determine the absence of the traumatic fracture, and therefore disturbed the bone fragments. The in situ x-rays provided a clear picture of a purely heat-traumatized bone. The interest of this latter fact was that the remains received by the physical anthropologist are frequently disturbed; an obstacle which can be overcome if careful reconstruction is performed.

A simple comparison of the temperature fluctuations for the blind test, recorded by my colleague, and with the opposite leg cremated at 450°C, demonstrated an interesting pattern (Figure 7a). The flashover pattern was similar in shape even at substantially different temperatures. Recall that #238L was placed in a cold oven and heated to 450°C and then cremated for half an hour. The opposite leg, #285R, was placed in a hot oven at 850°C, and cremated for one hour.

Figure 7b demonstrates the relationship of the flashover patterns of three specimens cremated at 850°C. The two legs from specimen #4 are more closely related in pattern than with the third specimen #285R; however, the degree of flashover is similar, with an average increase of 80° Fahrenheit for a ten minute period, before the decrease in temperature to the prescribed oven temperature. There are also more fluctuations or secondary flashovers in #4, probably because of the amount of fat associated with this larger female.

To summarize, the blind test experiment on specimen #285R was analyzed as having no evidence of a traumatic fracture. This was, indeed, the case, as the bone was burned at 800°C, without any traumatic fracture.

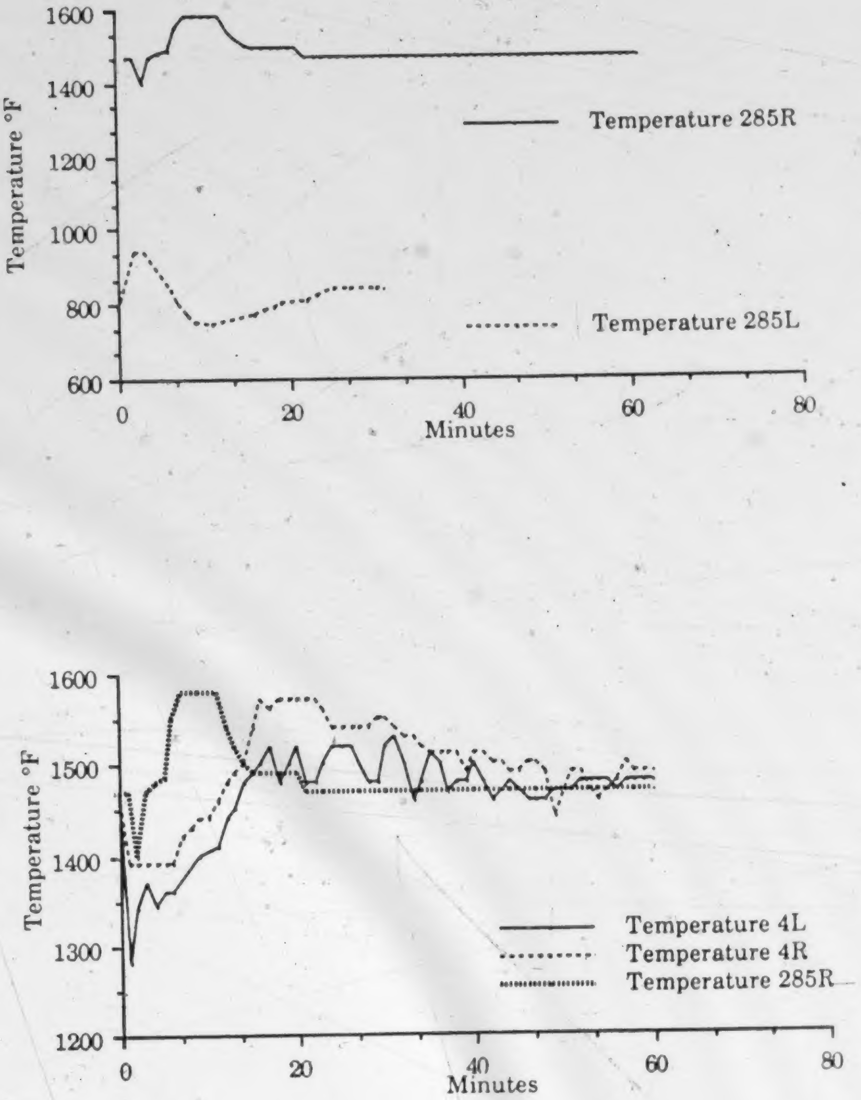

Figure 7: Temperature fluctuations II: a) This graph demonstrates the temperature fluctuations of the right and left legs from the same specimen cremated at different temperatures (800°C and 450°C), respectively. b) This is a comparison of the fluctuations in temperature of the three specimens cremated at 800°C.

4.7 Implications and Limitations

There are several caveats which must be accepted, when the interpretations from these studies are put to practical use. The first and most apparent is the confidence with which these data can be transferred to human bone tissue. The limitations of the material imposed upon this research relate to species, age, and sex of the specimens. As for species, only further comparative research with human tissue will reinforce these results. However, as discussed in the methodology chapter, the density of the compact bone is comparable in sheep and humans. The differences in the bone biomechanics between species of mammals is not likely to be significant enough to distort the interpretations.

None of these animals were fully matured skeletally, although they were, for the most part, past reproductive maturity. The change to adult bone tissue involves the remodelling and increase in the concentration of secondary osteons. This development will produce a greater amount of interstitial lamellae, and therefore lower bone strength and a reduced ability to withstand fracture. This difference would probably be most marked by observation at the microscopic level.

This discussion has been limited to two types of traumatic fractures in one type of bone. The propagation of fractures in different bones, such as the cranium, or pelvis, is likely to be somewhat different, because of the different structural design and function of these bones (Gurdjian, 1950; Schaffler and Burr, 1988). This research project was not designed to incorporate irregular bones or cranial bones; therefore the results presented here may not be directly transferable to interpreting traumatic fractures in these types of bones.

Another condition which was not addressed by this study was the identification of infarctions. The incomplete fracture would be extremely difficult to identify based on observations in this study. As demonstrated by the blind test, the confusion arising from the nature of HI fractures as compared to an incompletely fractured bone was considerable. The presence of infarctions in adult bone is considerably less than in juvenile tissue, and its presence should not necessarily be considered an important source of error.

Finally, the determination of whether the trauma was produced before, during, or after death can not be established in this study. The animals were all traumatized after death; and so no vital, hematomic reaction could occur. This is one problem which will continue to present itself, as production of experimental antemortem trauma is an unlikely option in future research.

4.8 Summary

In this chapter, a discussion was presented regarding the manner in which heat-induced and traumatic fractures can be differentiated (Table 7). It is necessary to approach this problem through a number of steps, including: 1) in situ observation and recovery, 2) reconstruction, 3) description of HI fractures; and 4) observation of the characteristics of traumatic fracture including 5) impact points and 6) congealed fluids and x-ray characteristics.

Procedure
1.In situ viewing and photography
2.Reconstruction of cremated bone
3.Analysis of heat-induced fractures
4.Analysis of traumatic fractures
5.Observation of impact point
6.Observation of congealed fluids and x-ray comparison

Table 7: Fracture Identification Procedure

The value of the time taken to complete this analysis must be based upon the probability of the presence trauma and the need to identify it. For example, although there is a good chance of identification of trauma in house fires because of the lower fire temperatures, there would not likely be a large chance of traumatic injury unless foul play is suspected. Air crashes, on the other hand, would have a high incidence of trauma but low chance of identification, because of the high temperatures associated with the crash and the reduced chance of the good recovery of remains. The researcher should make the decision to proceed with the analysis after consideration of its potential value.

CHAPTER FIVE

CONCLUSIONS

In these closing statements, it is time to reconsider the first chapter and the aim of this study. The intention was to provide experimental evidence to test the question of whether traumatic fractures can be identified in cremated bone. The analysis of the evidence has provided a direction in which to advance the study. The observation of cremated remains is valuable to understanding the events surrounding a cremation.

The need for information pertaining to trauma is demonstrated by the existence of cases, both modern and historical, which have raised the question of the presence of intentional or accidental trauma in individuals who were subsequently cremated. Considering the goals of the Forensic Anthropologist: 1) the identification of human remains, 2) the improvement of interpretational methodology and techniques, 3) the advancement of knowledge available for interpretation, and 4) the provision of a legal basis for such interpretations, the foregoing study has been directed towards the initial three goals. The success of this research in meeting these goals will be found in its acceptance and use by the medico-legal community, or by its acting as a catalyst for research into more sophisticated analyses.

The information available to the Forensic Anthropologist for the interpretation of cremated remains is multifaceted. There is, however, much work needed to clarify the meaning of the observations made concerning colour, size of the bone, and heat-induced (HI) fracture patterns; and how these observations can aid in positive identification of the individual and more detailed observations of the effects of intense heat on bone. Fire temperatures and the position and state of the body may all be analyzed more satisfactorily once it is fully understood how extreme temperatures affect bone tissue.

Analytical techniques used on non-cremated material (often with a certain amount of apprehension) have been applied to cremated bone with, in most instances, only minimal concern for their inadequacies, because better suited, more reliable techniques designed specifically for cremated human material are generally unavailable. Age, sex, stature, and race estimations must be completed with some knowledge of the possible sources of error introduced by shrinkage, warpage, and fragmentation.

The testing and reporting of techniques used experimentally and in case work is vital to the advancement of the interpretation of cremated human remains. The feasibility and reliability of proposed techniques needs to be discussed by those individuals using them, in order to establish research directions and priorities.

When presented with the possible occurrence of intentional or accidental trauma in association with cremation, previous research has been of little use. There have been no studies directed specifically at differentiating traumatic fractures from HI fractures. The conclusions and analytical techniques presented in Chapter Four are initial attempts to view the problem, and establish the potential for further research.

The chance of traumatic injury is high in today's fast-paced environment. An understanding of the sources of injuries and the embodiment of those injuries is necessary when attempting to search for such trauma in cremated material. The differences between accidental and intentional trauma must be considered when searching for evidence of them.

Also vital to the interpretation of cremated bone is an extensive knowledge of bone tissue and its structural organization. Bone tissue is complex, and is by no means fully understood. Questions still exist regarding the nature of the inorganic mineral component, and how it is associated with the organic components. Mineralization, possibly involving more than one phase of bone material (Posner and Beebe, 1975), may significantly alter the potential response to trauma.

This study has emphasized the effect of trauma on cortical bone, and briefly discussed problems relating to cancellous bone trauma in regard to cremated bone. Cortical or compact bone is a flexible material when healthy; but once the removal of water and organic components begins, there is a decline in its resistence to stress. The anisotropic characteristic of bone tissue is lost at this point; and the tissue is no longer ductile, but must be viewed structurally as a brittle material. The implication of this statement is that the bone's response to precremation trauma, (ie. fracture in a ductile material) will be different from heat-induced trauma (ie. fracture in a brittle material). Therefore, it is logical to assume that at some level of structural organization the two types of fractures should be distinguishable. Proceeding with this assumption, analysis at the gross morphological level provides evidence in support of this statement, at least in compact bone tissue. Cancellous bone tissue has proved to be more difficult to analyze.

Compact bone, which has not been exposed to increased temperatures, will fracture in structurally weak areas, such as in poorly mineralized cement lines or in the interface between lamellae. Collagen bundles may redirect the route of the fracture, as well as features such as the canaliculi, lacunae, and Haversian canals. It is important not to forget that these structures are composed of organic substances in association with the bone mineral. If the organic component is removed, what remains to direct or stop a fracture? The crystalline latticework of bone mineral is not pyrolized with increased temperatures; and therefore remains, in some form, to respond to stress.

Unfortunately, the knowledge available at present concerning fracture propagation in bone tissue is not definitive. Many questions remain regarding the ability of each of the bone's components to respond to dynamic or static stress. Stress testing has established at what point failure will occur, or how repeated stress below the yield point will result in fatigue fractures; but there is little understanding about which components are likely to fail first, and how and why they fail. If the observations of fracture propagation on unburned bone are so vague, it is no surprise that even less is understood about fracture propagation in cremated bone.

Previous research has provided some information concerning the change in the nature of the organic and inorganic components of bone exposed to heat. The bone tissue is thought to undergo a series of changes similar to those recorded for ceramics. This process, labelled the DDIF process, includes the dehydration of water, the decomposition of the organic components of bone, the inversion of the hydroxyapatite-like bone mineral to ß tricalcium phosphate, and the loss of carbonates through pyrolysis; and finally, fusion of the remaining crystalline structure. These stages are related to the degree of heat exposure; therefore stage 1 occurs between approximately 105°-500°C, while stages 2 and 3 range from 500-700°C, and 700-900°C, respectively. The final stage begins after 900°C, and continues until the crystals melt by 1200-1400°C. The loss of the organic components and the inversion of the minerals will affect the propagation of a fracture, as the features thought to arrest fractures (ie. lacunae and canaliculi) do not remain structurally sound. Some evidence (cf. Susini et al., 1988) suggests that fractures originate in these weakened areas.

The knowledge presently available regarding the propagation of fractures, both traumatic and heat-induced, is insufficient to explain why differences exist in the gross morphology of the fracture types. Microstructural analyses are necessary to verify the biomechanical and structural differences proposed in this paper. Previous research (cf. Krogman, 1943b; Thurman and Willmore, 1980-81; and Binford, 1963) of fracture patterns, determining precremation bone condition, are not conclusive. As these individuals were approaching their research from a gross morphological perspective, and were relating the origin of the fractures to the amount of attached soft tissue, they were working from the outward appearance to establish the internal nature of the bone tissue. The amount of soft tissue surrounding the bone prior to ignition relates directly to the amount of the organic components present. If sufficient soft tissue and fluids are present, then the bone will react to heat initially by dehydrating, while dry bone tissue will have already lost a substantial amount of physisorbed water. This development suggests that the material in the first case will be ductile in nature for a longer period than the latter, once exposed to heat. The fractures resulting will therefore reflect this difference. As previously mentioned in Chapter Two, the five types of bone tissue will each behave uniquely; and must be analyzed as distinct entities, with their own qualities. This study has emphasized the gross morphology of HI fractures viewed in compact bone; but has largely overlooked those in cancellous, periosteal, endosteal, and woven bone.

Comparison of the HI fractures with traumatic fractures has provided some insight into the processes involved in the cremation of bone tissue. It would now be of value to follow the pioneering steps of Baud *et al.*, (1986) and Susini *et al.*, (1988) by analyzing the biomechanical response of bone tissues from the inside out. This analysis would require the ultramicroscopic examination of fracture origins and paths in nonburned bone which has been traumatized, and those fractures produced in cremated bone by structural fatigue-induced by high temperatures. If these fractures propagate differently, because of the nature of the components present, then there will be an explanation for the gross differences described in this study. At present, there is only the theory presented here to explain characteristics which have been described for traumatic versus HI fractures in cremated compact bone.

The methodological approach presented in this paper was based upon observations of the fractures provided in fifteen experiments. The differences between HI fractures and traumatic fractures are based upon the distinctive characteristics established through gross and radiographic observations of traumatized and cremated bone tissue. The rational behind these differences, as has been discussed, is based upon the structural biomechanics of ductile and brittle materials.

The method which has been proposed to analyze cremated bone for evidence of trauma induced prior to cremation begins with in situ observations and records. The importance of this contextual evidence will benefit the researcher in assessing the material for trauma, but will also provide a spatial picture of the remains to assist in determining body position. The recovery of the remains must be as complete as possible, taking care with the removal and in-transit packaging. Once the remains reach the medical facility, they should be radiographed in order to provide a view of the remains encased in soft tissue or matrix. These x-rays will be valuable later in establishing bone movement and/or muscle contraction. The remains should be reconstructed as much as possible, when permissible.

Once the bone has been reconstructed, analysis of heat-induced fractures can begin. There are five main types of HI fractures identifiable in compact bone of the long bones. These include: a) the longitudinal fracture, b) the curved transverse, c) the straight transverse, d) the patina, and e) the delamination fractures (see Table 6). All but the patina fracture can be viewed on the x-ray. In the experiments completed here, the longitudinal fracture becomes extremely problematic when it radiates into cancellous tissue. The patina and delamination fracture patterns are often associated with the layer of lamellar bone overlying cancellous epiphyses. The curved transverse fracture is more often associated with specimens cremated at higher temperatures, while the longitudinal and straight transverse fractures are found at lower temperatures. There is no simple explanation for the difference in the literature references regarding the association of longitudinal and straight transverse HI fractures with dry bone cremation (Binford, 1963). Clearly, they are not limited to that material, but are associated also with fleshed remains. The precremation condition of the bone (ie., desiccated) will likely influence its burning pattern (ie., removal of organic components). The reason probably relates to the microstructure of the tissue.

The next step in identifying precremation trauma in burned bones requires the intimate knowledge of the three forces (tension, compression, and shear) which produce fractures; and the types of fracture patterns to be expected when these forces (and their variations) are in action. The transverse traumatic fracture is the simplest to identify in cremated bone, and it has a horizontal fracture margin which extends around the circumference of the bone. The transverse traumatic fractures produced in the experiments were frequently visible in the in situ radiographs, when soft tissue was still associated with the bone.

Spiral traumatic fractures are identifiable by the presence of an helical fracture around a continuous margin of the bone at a 45° angle. The spiral fracture is problematic, and can be confused with longitudinal heat-induced fractures. One should look for evidence of fractures which have been arrested by a previously formed fracture. This feature will provide evidence of the sequence of their production; and since the traumatic fracture occurs before the heat-induced, it should be possible to establish potential locations for the spiral.

The fourth feature to search for on the surfaces of the bones is the the point of impact. If an impact point is located, then precremation trauma has occurred. The static force applied to cremating bone will not produce flakes or depressed areas characteristic of impact points. The bone will fail in the manner described previously. The impact point is produced by an external force, not an internal one; and is reminiscent of flakes described in bone tool production.

Congealed fluids and tissues may also be observable on traumatic fracture margins. These features may represent the release of blood and fluids into the surrounding muscle and hard tissue surfaces at the time of fracture. These newly exposed surfaces would be coated and the fluids baked onto this surface early in the cremation. Once the bone tissue is exposed to the increased temperature for a substantial time, the bone becomes calcined and all organic material is pyrolized. This development would remove evidence of crystallized fluids, except in areas which remain carbonized.

This methodological procedure is not designed to exclude the possibility of traumatic fracture, but to expose evidence which may verify its presence. Therefore, absence of these characteristics does not preclude the possibility that excessive fragmentation, poor recovery, and reconstruction have destroyed the potential evidence of trauma.

One limitation of this study has been the use of non-human material to describe a methodology to use for human remains. The justification for the use of sheep femora in this study can be found in Chapter Three, so it will not be restated here. However, it is necessary to discuss the valid criticism that will arise, regarding the transfer of observations on a quadruped long bone to a human one. The physiology of these two species is not identical; but it is assumed here that because bone density is similar, and mammal bone is comparable, the results will be of value.

Obviously, testing of the methodology and conclusions on human bone tissue is necessary. It is also important to consider the fact that the bone tissue used was not fully mature; and may respond to trauma and heat differently than mature bone. It is believed that this difference is not of great concern, because the HI fractures were similar to those described in other studies, and the traumatic fractures were identical to those seen in human bone. Possible variations in the expression of heat fractures and the time and force required to produce traumatic fractures are expected in adult and juvenile bone. Only further comparative testing will clarify this situation.

There is much research to be completed in the future to address the numerous questions arising from this study. Most important, however, is the completion of ultramicroscopic analyses of bone tissue fracture propagation, in order to substantiate or negate the theory provided here for the differences identified between HI fractures and precremation traumatic fractures. This problem can initially be explored through the use of the scanning electron microscope (cf., Schultz, 1986). It would also be interesting to include each type of bone tissue and various forms of bone (such as irregular and cranial) in the study. The structural response of each is expected to be somewhat different.

The future potential for cremation research is vast, as there are weaknesses in many areas of the methodology used in the interpretation of cremated bone. The problems which arise in the analysis of human cremated remains in the medico-legal community will not decline unless more research is directed at answering those questions which have not been adequately addressed at this time. This is an area of research which is open and waiting to be explored, and much of the ground work has been completed in the last 100 years. It is now time to determine the viability and accuracy of methods used in the past. Problems such as trauma identification, sex, age, stature estimation, body position, fire temperature, events prior to cremation, and recovery methods still require research and experimentation to provide both the anthropological community and the medico-legal community with reliable techniques.

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PLATES

Plate 1a: Fire-asane furnace.

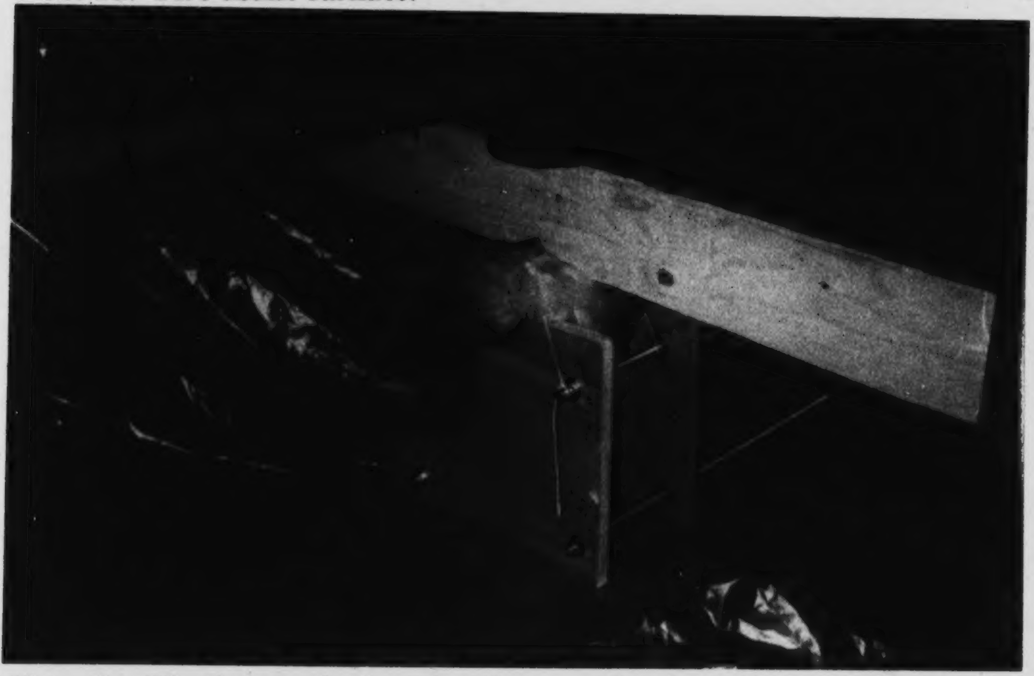

Plate 1b: The first method used to fracture the sheep femora transversely is demonstrated in this photograph. The maul, on a pivot, descends from 180° to contact the plywood resting transversely across the femoral shaft.

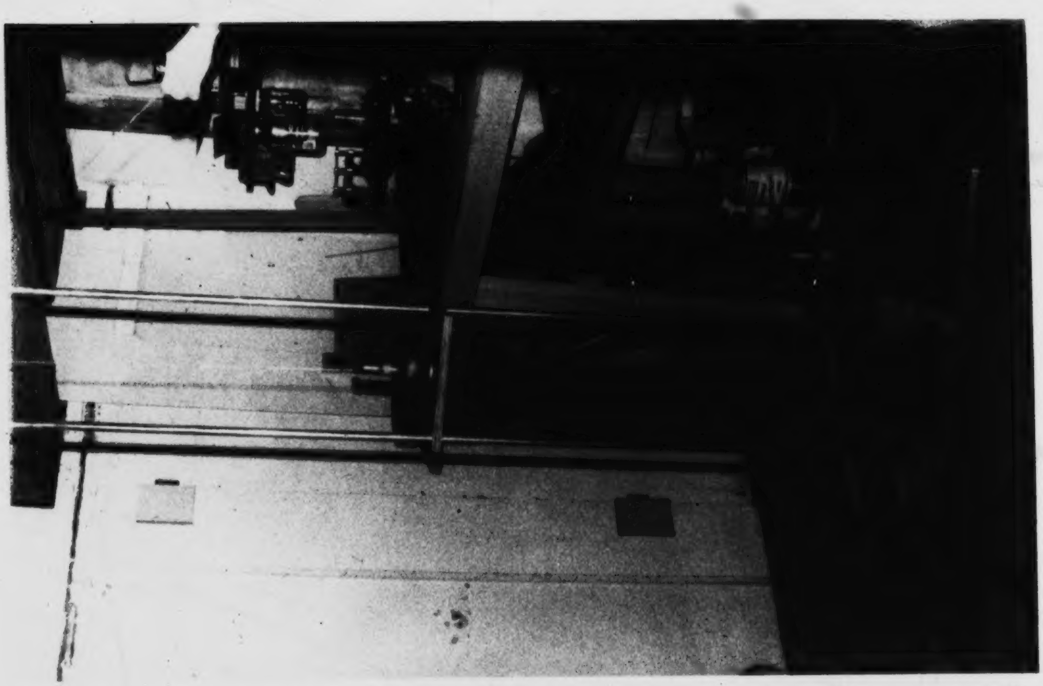

Plate 2a: The second method used to traumatize the sheep femora was the guillotine, and this method produced the spiral traumatic fractures.

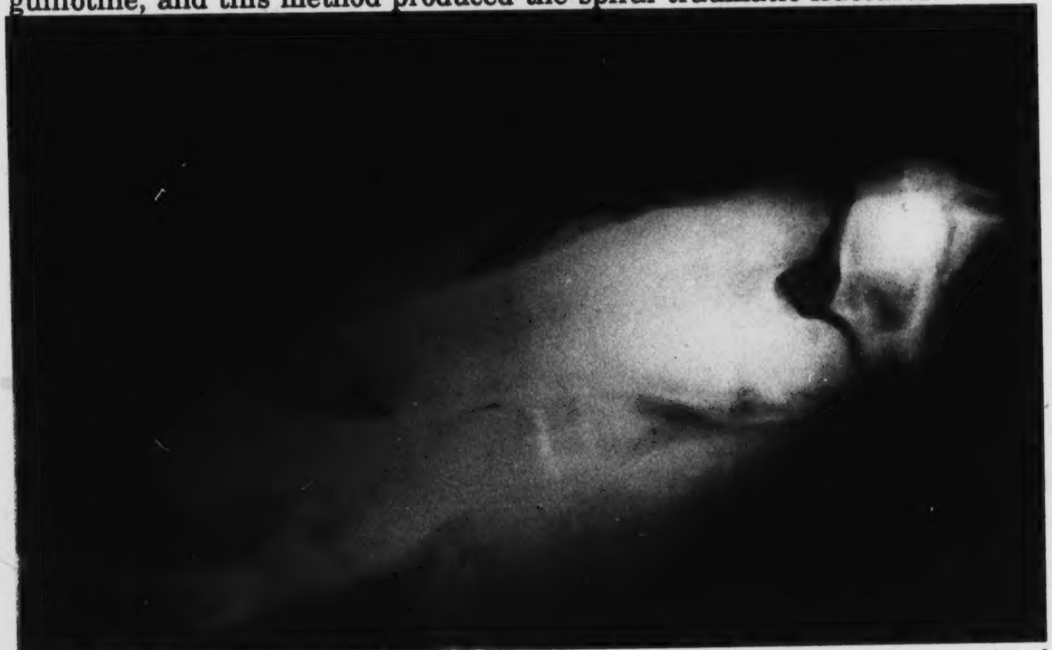

Plate 2b: Contraction of the muscle tissue, and the overlap of the proximal and distal portions of the femur is viewed in the in situ radiograph of specimen #285L, cremated at 450°C.

Plate 3a: The transverse traumatic fracture can be located at midshaft of this severely calcined specimen #78L, which was cremated at 900°C.

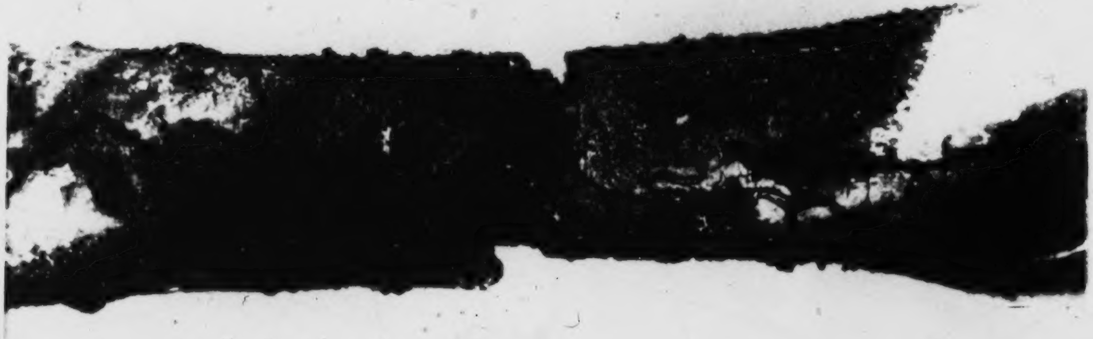

Plate 3b: Reconstruction of specimen #150L demonstrates the transverse traumatic fracture located at the midshaft. The discontinuity in a longitudinal heat fracture is evident at the traumatic fracture margin.

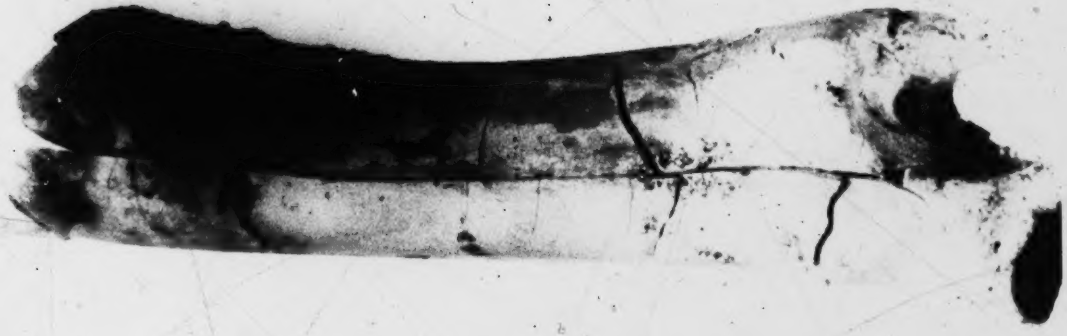

Plate 4a: The longitudinal HI fracture is located in the midline of the anterior surface and is intersected by straight transverse HI fractures periodically. #213L was cremated at 850°C, is grey-white and carbonized.

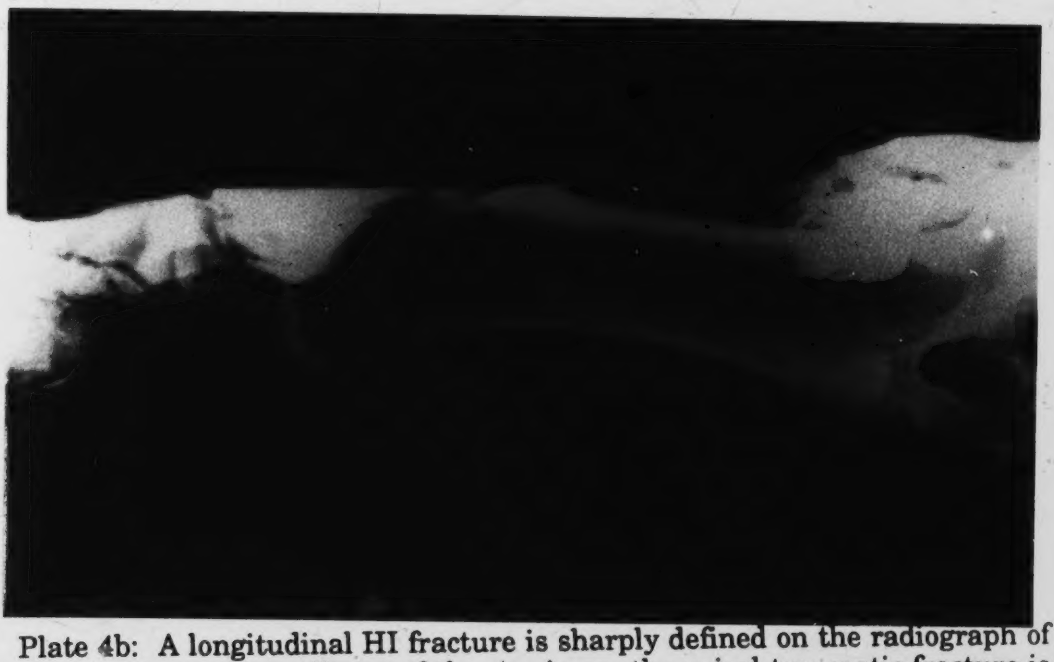

Plate 4b: A longitudinal HI fracture is sharply defined on the radiograph of #213L. Due to the collapse of the specimen, the spiral traumatic fracture is not clearly demonstrated.

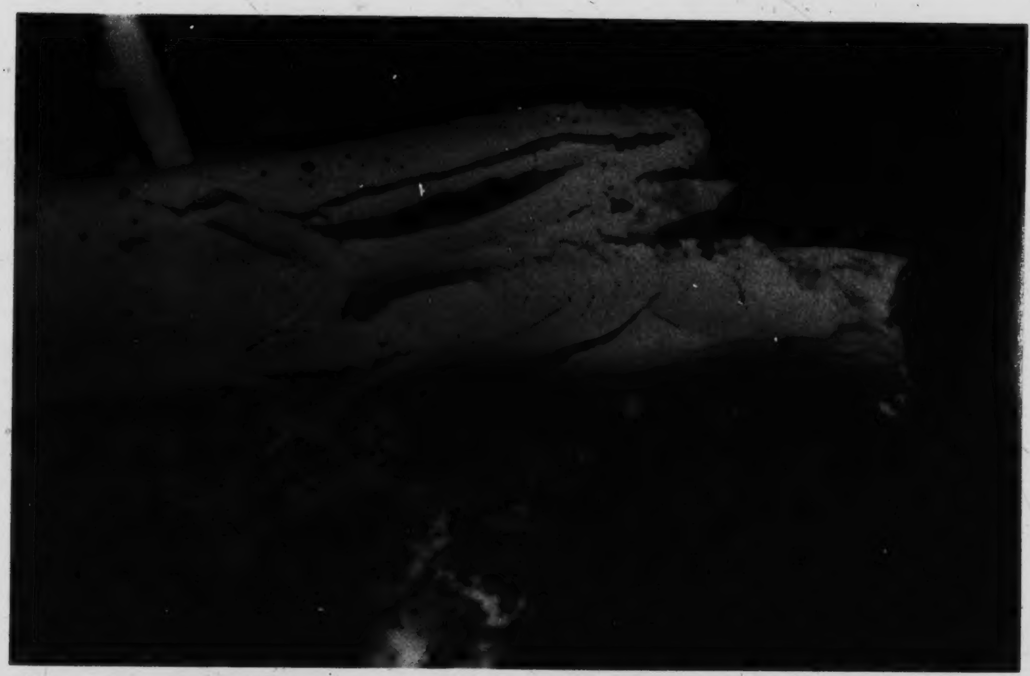

Plate 5a: Curved transverse HI (thumbnail) fractures and warpage are demonstrated on the tibial fragment of #78R, which was cremated at 900°C.

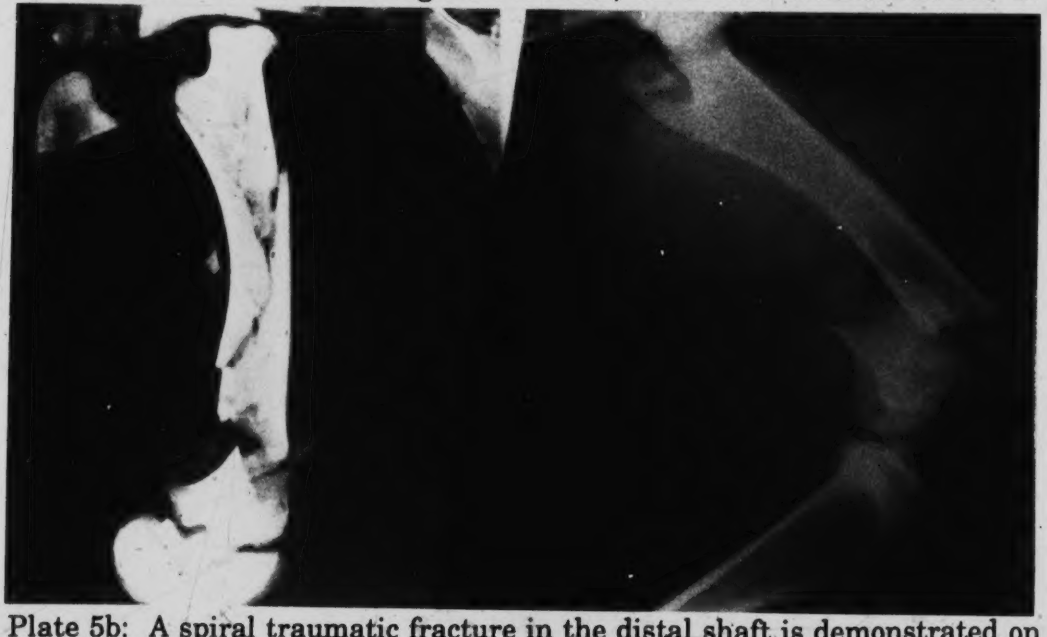

Plate 5b: A spiral traumatic fracture in the distal shaft is demonstrated on the post-trauma (right) and post-cremation (left) x-rays of #538R. Longitudinal HI fractures radiate from the shaft into the proximal cancellous tissue.

Plate 6a: Curved transverse HI fracture in #78L (900°C) is concave on the superior margin and convex on the inferior margin.

Plate 6b: The curved transverse HI fractures are stacked in the x-ray of #78L, and there is a separation of one fragment.

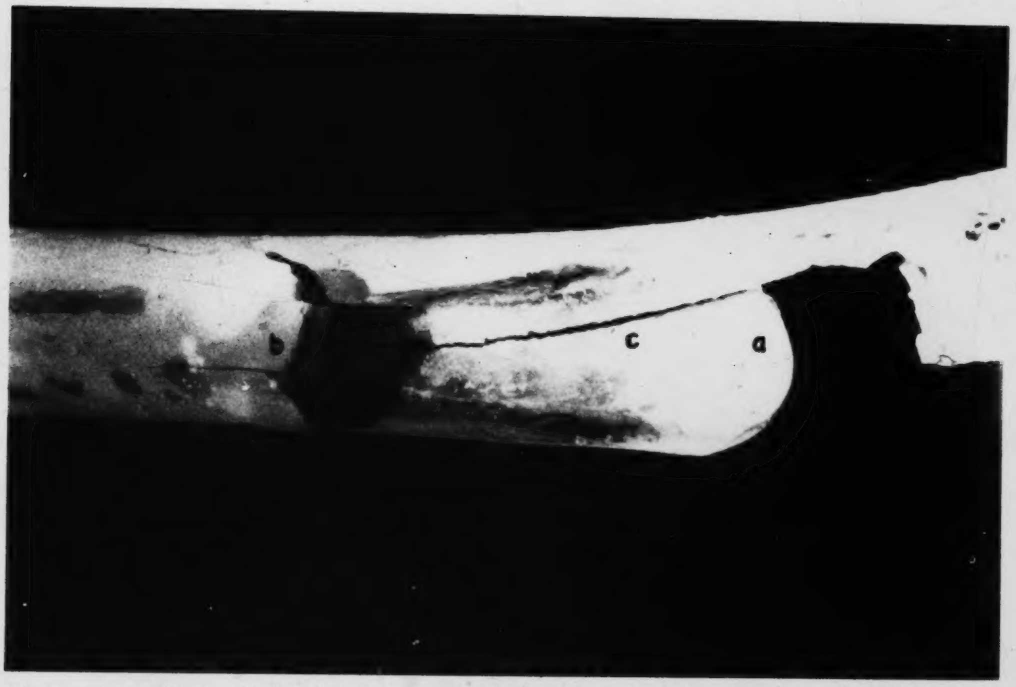

Plate 7a: Tibia of #538R demonstrates a) curved transverse, b) step, and c) longitudinal HI fractures.

Plate 7b: X-ray of tibia #538R (750°C)

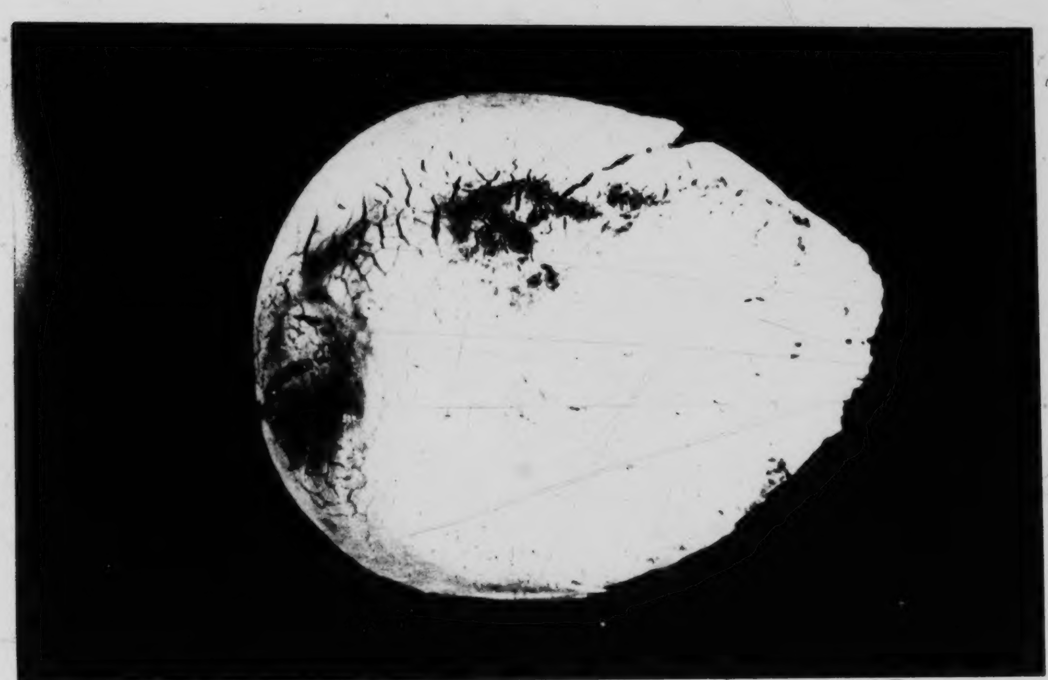

Plate 8a: The patina fracture which is similar to the crazing of china is on the femoral head; this fracture does not extend deeply into the bone.

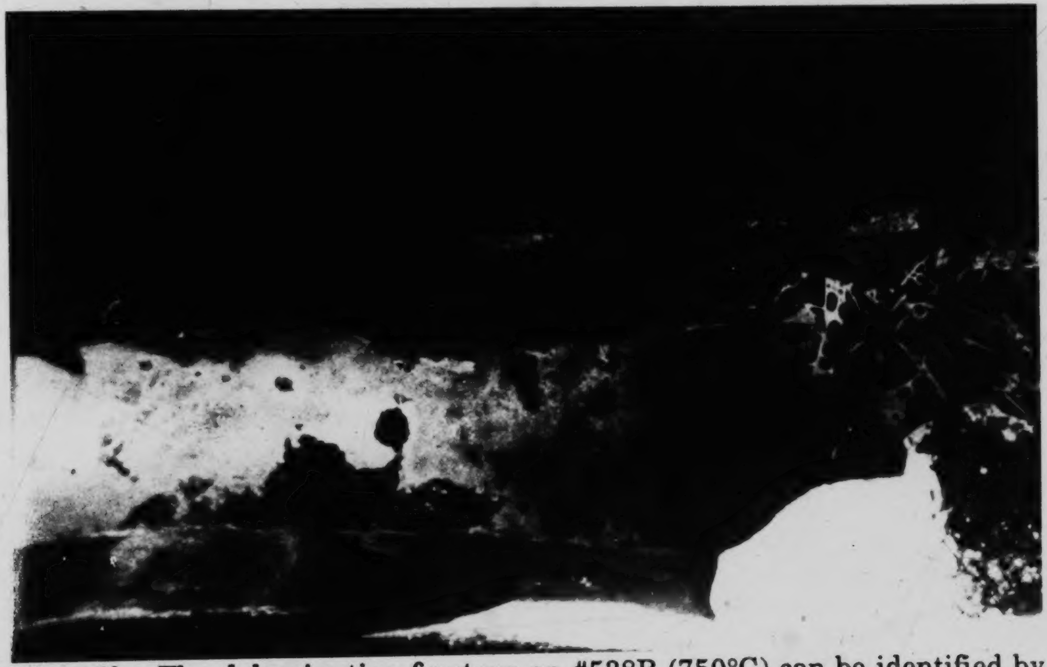

Plate 8b: The delamination fracture on #538R (750°C) can be identified by the splintering of layers of cortical bone.

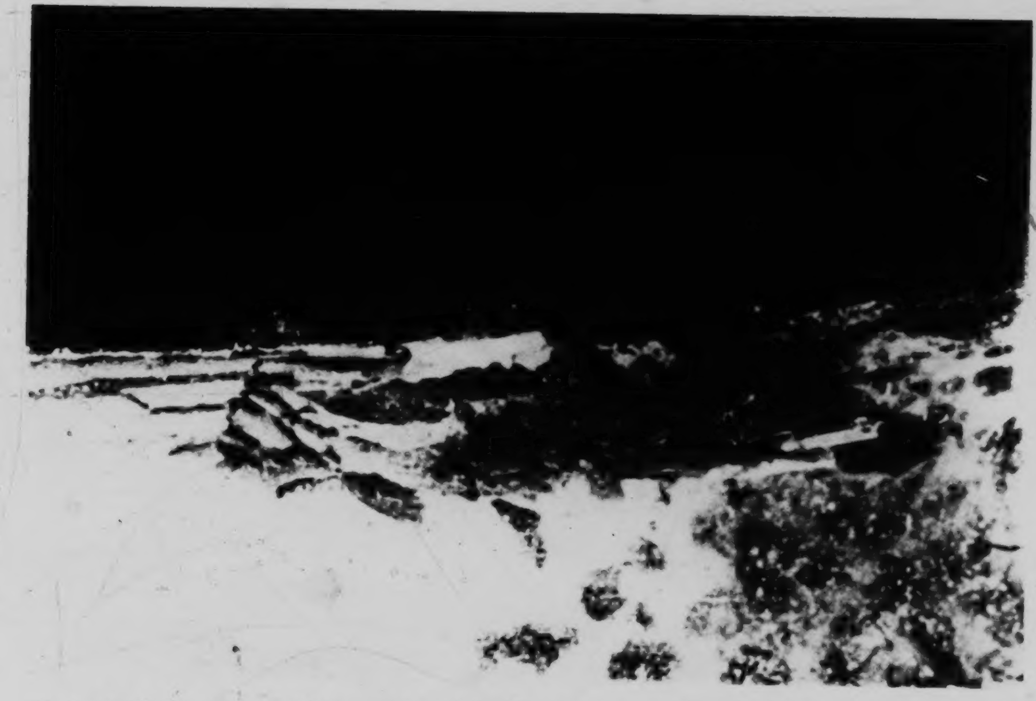

Plate 9a: Close-up of the delamination on specimen #538R.

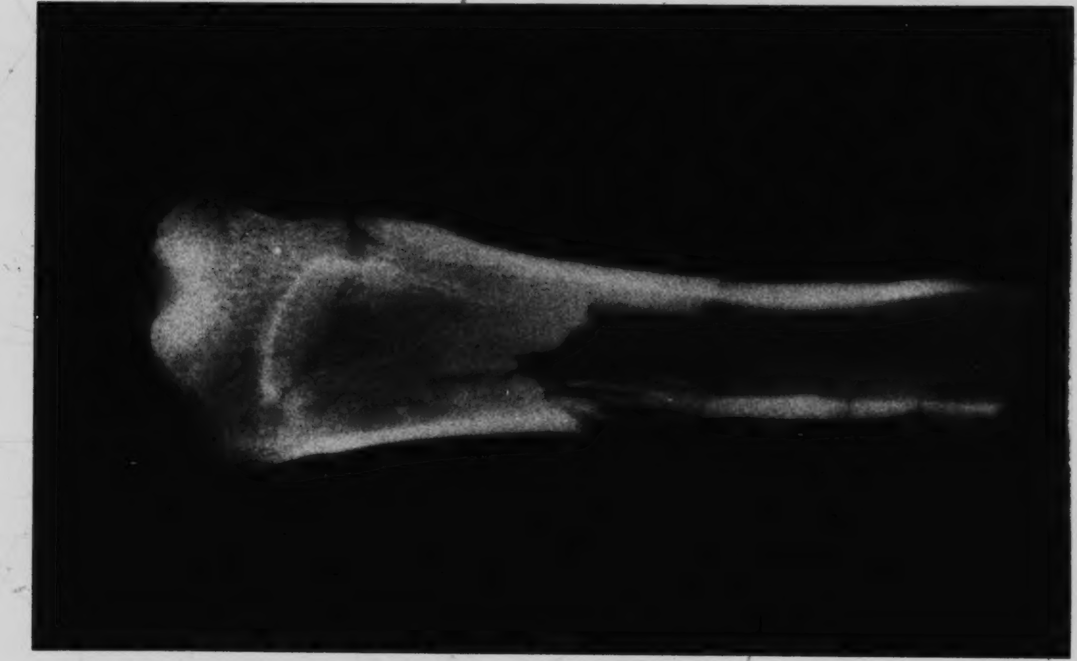

Plate 9b: Delamination is identified by the buckling of the cortex in this x-ray view.

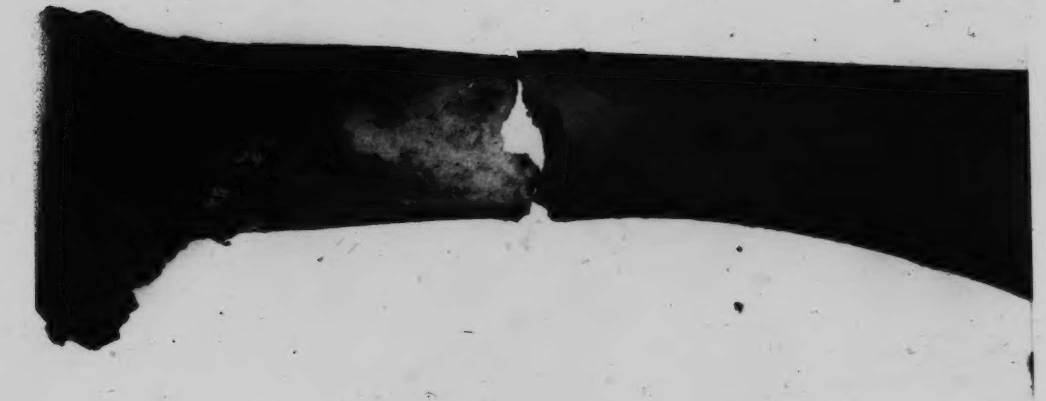

Plate 10a: The transverse traumatic fracture of #147L extends around the entire circumference of the bone; and there is an impact point at this location (650°C).

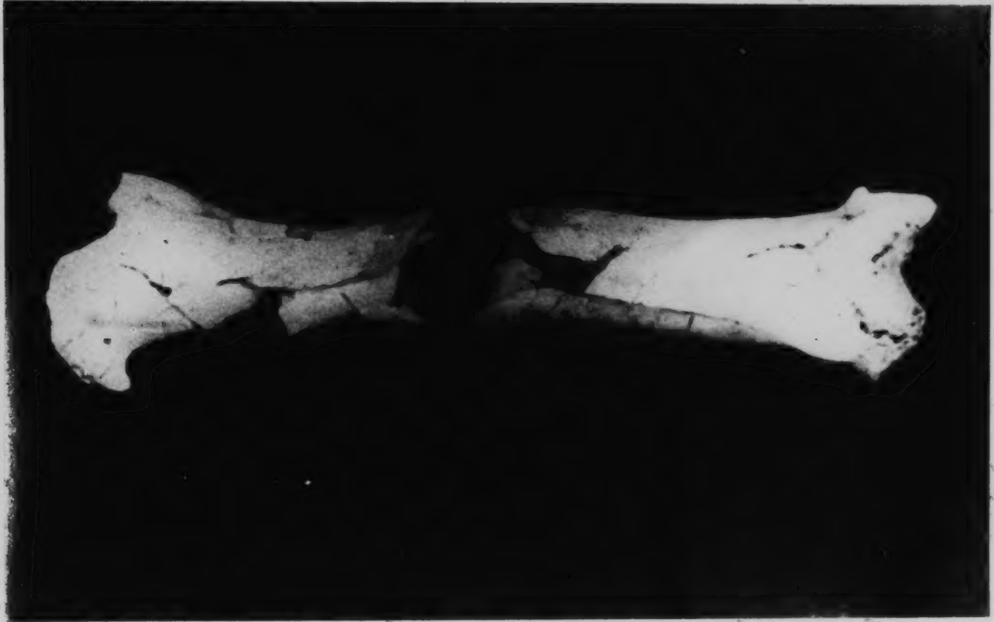

Plate 10b: The transverse traumatic fracture is viewed in this reconstruction of a severely calcined bone; warpage prevents the articulation of the margins and no impact point is evident.

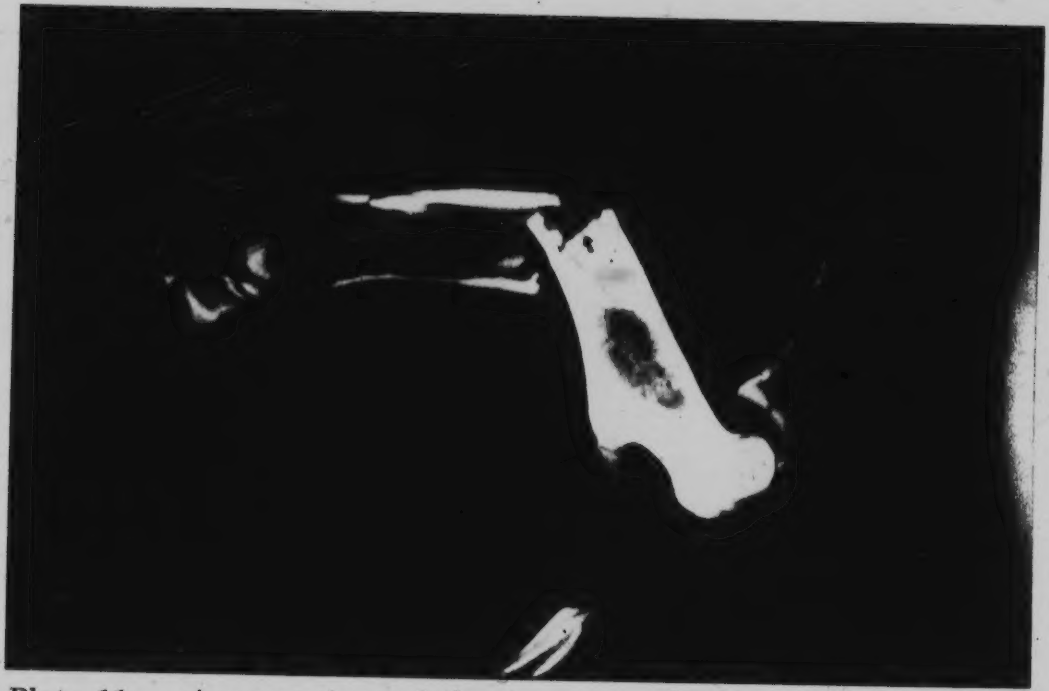

Plate 11a: A comparison of the transverse fracture margins and the longitudinal HI fracture margins located on the distal shaft of this in situ radiograph of #150L demonstrates the indistinct margins of the traumatic transverse fracture.

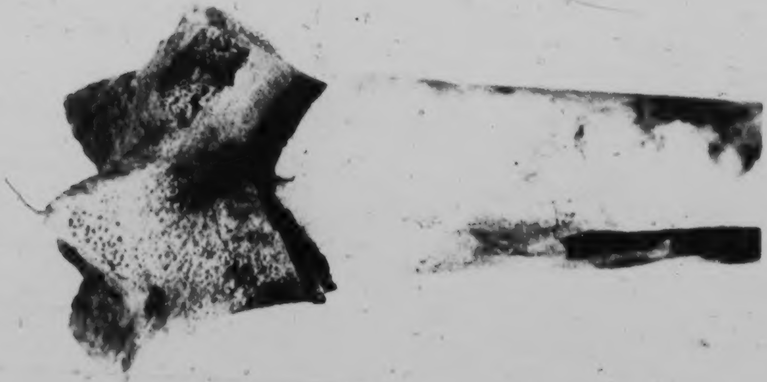

Plate 11b: A spiral traumatic fracture is demonstrated in the cancellous tissue on the medial surface of #538R.

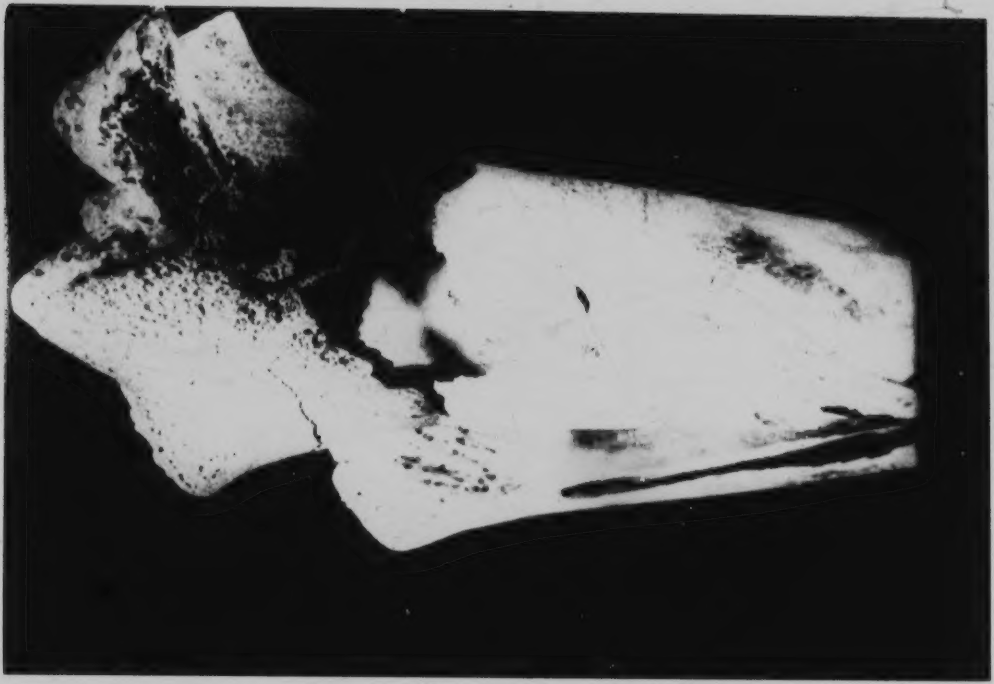

Plate 12a: The 'punched in' impact point is demonstrated on the lateral surface of #538R; curved transverse HI fractures and warping are visible.

Plate 12b: A reconstructed spiral traumatic fracture is at the midshaft of #213R (850°C). Longitudinal and straight transverse HI fractures are visible.

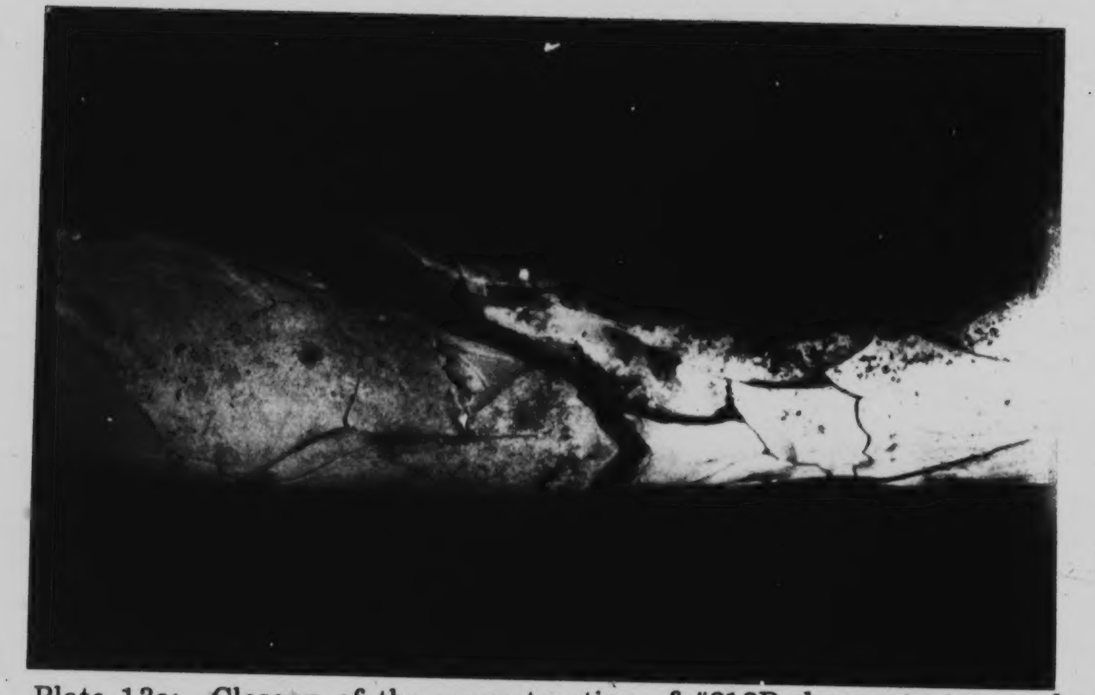

Plate 13a: Closeup of the reconstruction of #213R demonstrates good articulation; and the longitudinal fracture on the proximal shaft (right) does not continue into distal shaft.

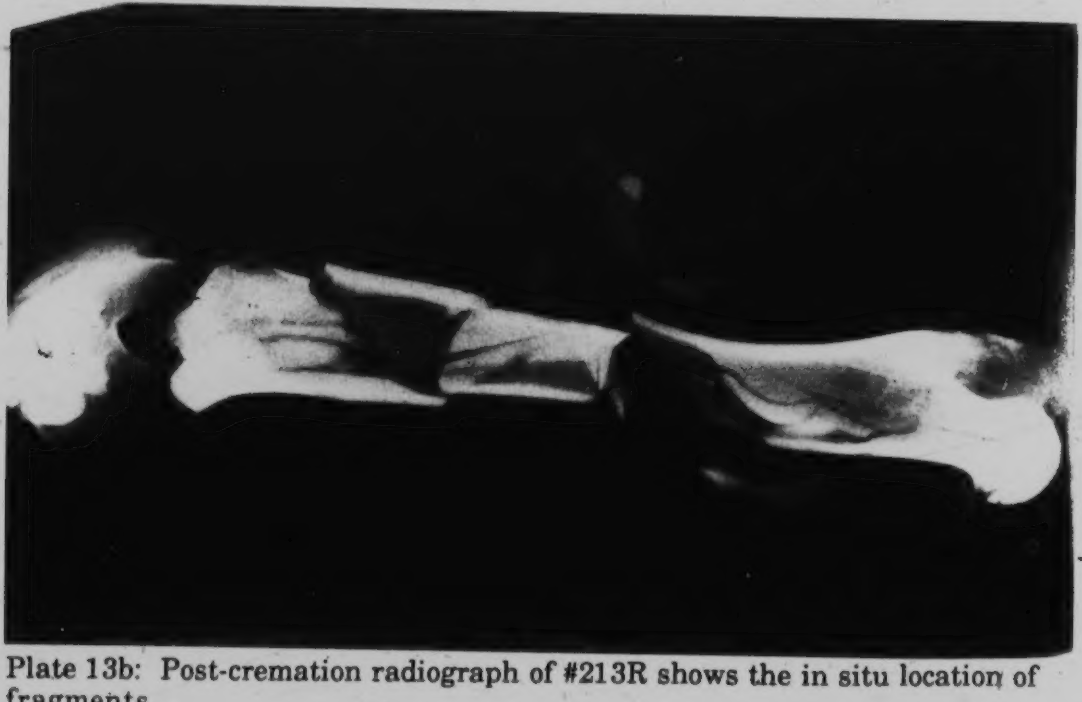

Plate 13b: Post-cremation radiograph of #213R shows the in situ location of fragments.

Plate 14a: In the post-cremation (left) and post-trauma (right) x-rays of #150R (600°C) the spiral traumatic fracture can be easily located at the arrows.

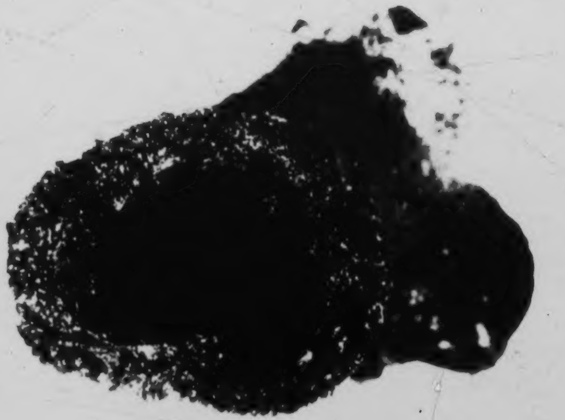

Plate 14b: Crystallized fluids are located on the traumatic fracture margin of #150L.

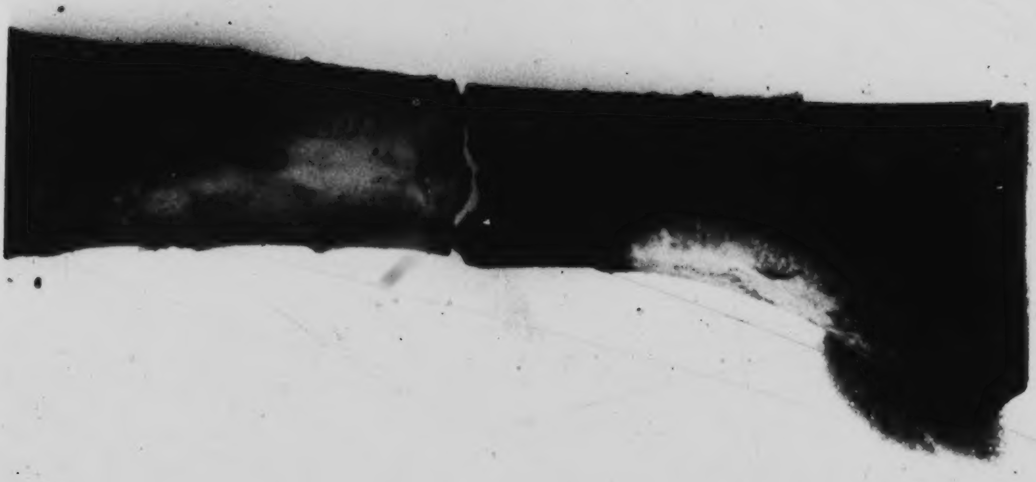

Plate 15a: A depressed flake is found at the impact point of #538L (750°C); compare specimen with plates 12a and 5b. #538L has a transverse traumatic fracture.

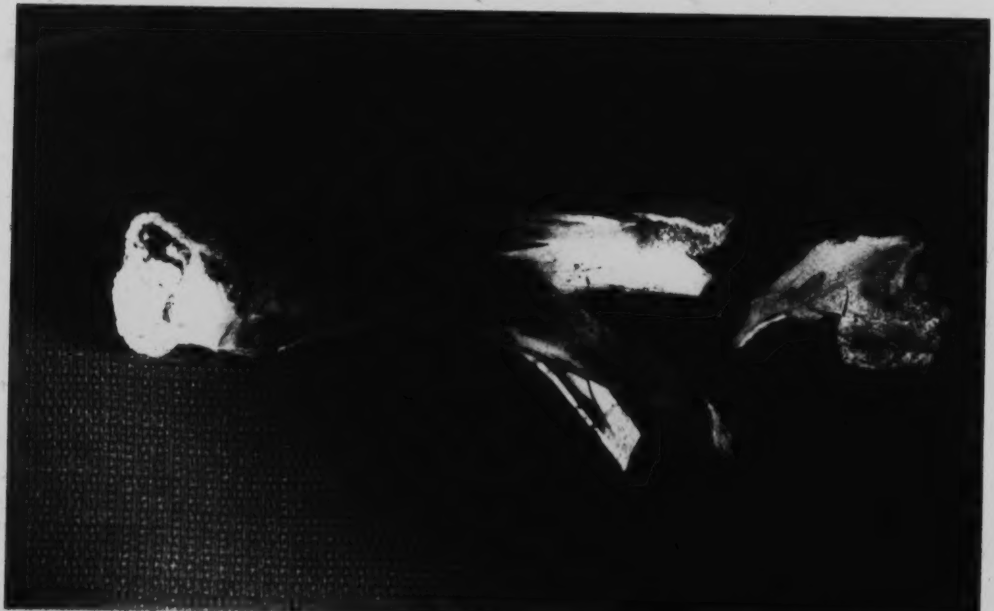

Plate 15b: Reconstructed blind test specimen #285R (800°C) has no evidence of a traumatic fracture; the two segments articulate at HI fractures. Fragments #11 and #12 (see Figure 6) can be seen on the distal portion.